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PROPULSION TECHNOLOGY

OAST Summer Workshop

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Vol. V of XI

NOTICE

The results of the OAST Space Technology Workshop which was held at Madison College, Harrisonburg, Virginia, August 3 - 15, 1975 are contained in the following reports:

EXECUTIVE SUMMARY	
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VOL III	NAVIGATION, GUIDANCE, AND CONTROL
VOL IV	POWER
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VOL VII	MATERIALS
VOL VIII	THERMAL CONTROL
VOL IX	ENTRY
VOL X	BASIC RESEARCH
VOL XI	LIFE SUPPORT

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Title: Laser Heating of Propellants

Objective: Evaluate the concepts and establish the potential feasibility of propulsion by direct heating of propellant via a laser beam transmitted from a remote source.

Description: The system would contain a laser source and associated steering system and an on-board thrust system which would receive the laser beam and efficiently convert the beam energy to sensible propellant enthalpy. Propellant is then expanded to high exhaust velocity.

Justification: The unique characteristics of laser light offer the potential of efficient transmission of large quantities of energy through space. Absorbtion of this energy and subsequent conversion into useful propellant work presents an advanced option for mission capability by having a remote energy source and independent control of specific impulse and choice of propellant. Laser powered systems offer the possibility of specific impulse well in excess of 1000 seconds.

Title: Laser and Microwave Electric Propulsion

Objective: To complete the experimental characterization and conceptual design laser and microwave power transmission and conversion in space for primary electric propulsion.

Description: Visible wavelength laser energy and/or microwave beamed energy from an orbiting spacecraft or other remote site is transmitted to other vehicles (orbiting satellites or surface rovers) and is then converted to electrical energy to be utilized for propulsion. Conceptual definition is required for proper evaluation of the technology.

Justification: The proposed technology represents an opportunity, among other applications, to utilize "mother-daughter" vehicle operations at the outer planets, where solar power is not available. In order to adequately compare this technology to other systems carried to a higher level of the state of the art, advancement of the technology is essential. If the resulting concepts prove to be promising, further technology advancement can then be recommended.

Title: Auxiliary Electric Propulsion System with Mercury Bombardment Thrusters

Objective: To bring to a state of demonstrated technology readiness attitude control and stationkeeping systems for geosyncronous satellites using mercury bombardment thrusters.

Description: The auxiliary electric propulsion program consists of the technology demonstration of subsystem elements; integration of these elements into a system, definition of system interfaces, and verification of system performance parameters, lifetime and reliability. The major elements of an auxiliary propulsion system consist of a thruster, power processor, thrust vectoring subsystem, propellant supply and distribution system, and associated structural and thermal control elements. North-South stationkeeping is required for most geosyncronous satellites and becomes particularly important for advanced three axis stabilized systems in order to improve overall ground and space system costs.

Justification: The potential advantages of a high specific impulse electric propulsion stationkeeping system have been documented by many studies. In particular, large mass savings and improved precision of control for geosynchronous satellites may be obtained by use of this technology.

Title: Solar Electric Primary Propulsion Thrust Subsystem

Objective: To bring to a state of technology readiness a primary solar electric propulsion thrust subsystem with mercury bombardment thrusters.

Description: The Primary propulsion subsystem technology program consists of the technology demonstration of the several key subsystem elements; integration of these elements into a representative subsystem; definition of the subsystem interfaces; and verification of subsystem performance parameters, lifetime, and reliability. The major subsystem elements include mercury 30-cm electron bombardment thrusters, power processors, thrust vector mechanisms, thrust sybsystem controller, an electrically isolated propellant aupply and distribution system, and appropriately scaled solar array system.

Justification: Many studies have shown the benefits--both in terms of performance and expansion of the NASA mission set capability--of the use of a high specific impulse, high performance propulsion system. In particular, significant payload and performance benefits accrue via use of this technology for high energy, performance sensitive missions, such as interplanetary transportation for out-of-the ecliptic and comet rendezvous, and low-earth to geosynchronous orbit and on-orbit operations for large space systems. Other characteristics, such as low thrust and variability of operating performance parameters, allow for precision in trajectory and attitude control and increased flexibility in launch opportunities for selected missions.

Title: Electric Propulsion with Low-Molecular Weight Propellants

Objective: To provide the technology for low cost, high specific impulse, low-molecular weight propellant propulsion systems for transportation and on-orbit operations for very large space systems in near earth environment.

Description: This technology program would first provide the critical element technology for a low-molecular weight propellant electric bombardment thruster propulsion system using the solar electric mercury thruster system technology as a baseline. Sufficient thrust subsystem parametric data would be obtained to allow timely-low risk technology transfer to very large electric propulsion systems which utilize high thrust density MPD electric thruster systems with the same light fuels.

Justification: The development of the shuttle earth-to-low orbit transportation capability will allow the use of a very large space system to satisfy a large variety of national requirements and priorities. The transportation and on-orbit operation of the large space systems require very high energy propulsion systems and large amounts of propellant. The use of plentiful, cheap, and inert propellants operated at specific impulses between about 3000 and 10,000 sec. will significantly decrease costs and the overall environmental impact over that with chemical systems.

Title: Solar Heated Hydrogen Propulsion

Objective: To develop technology for a propulsion system using solar energy to heat stored hydrogen for propulsion of a tug-type vehicle.

Description: Conduct conceptual design studies, system trade-off studies, and preliminary design of the system. Perform technology program covering the collector, receiver, thrusters, and other system components and conduct systems tests tests to bring technology to maturity by 1985.

Justification: Solar heated H_2 propulsion provides a low thrust, high specific impulse system suitable for transporting payloads from low earth orbit to geosynchronous orbit or escape velocity. The system is relatively simple and would have low development cost compared to competing approaches.

Title: Solar Sails

Objective: Acquire the technology for space application of very large solar sails for interplanetary spacecraft.

Description: Aluminized mylar solar sails with area dimensions on the order of 1000m and a mass of 500-2500 kg for space vehicle applications is desired.

Justification: Solar sails, because no on-board propellants are required, can become very efficient for inner solar system missions. Solar sail mass, system lifetime, deployment reliability, and attitude dynamics are key to mission applications.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)a

1. TECHNOLOGY REQUIREMENT (TITLE): $F_2N_2H_4$ PAGE 1 OF 3

S/C Propulsion Subsystem

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Design, fabricate, assemble, and test a flightweight, blowdown bipropellant propulsion subsystem utilizing $LF_2N_2H_4$ for planetary spacecrafts.

4. CURRENT STATE OF ART: The feasibility of utilizing a fluorinated oxidizer and an amine fuel has been demonstrated in semi-heavyweight system.

HAS BEEN CARRIFD TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

In order to reduce mass, a demonstration utilizing fracture toughness techniques of LF_2 contained in Titanium is currently underway. Because of the constraint not to purposefully vent LF_2, thermal control techniques need to be demonstrated. Analysis indicates feasibility, but testing has not been undertaken. The main driver for this technology is the high specific impulse ($\sim$ 3700 $\frac{N\text{-}S}{KG}$ at $\sim$ 2700N thrust level). The thrust chamber to deliver this specific impulse is currently in design. However, an effort to reduce the mass of the thrust chamber must yet be undertaken.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. For high energy missions, specific impulse is a driving parameter. The use of LF_2/N_2H_4 represents a class of propellants in the non-H_2 category which is near the ultimate in chemical specific impulse.

b. Applicable to mission types M4, 5

c. The performance can be used in many ways. Increased payload; increase Δv ; shorter trip time; eliminate some upper stages; allow use of existing non-propulsion hardware.

d. The very least would be a complete ground-test of a flightweight system; a shuttle experimental flight test would be beneficial if cost-effective.

TO BE CARRIED TO LEVEL 8

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)a

1. TECHNOLOGY REQUIREMENT(TITLE): $F_2N_2H_4$ S/C Propulsion Subsystem

7. TECHNOLOGY OPTIONS:

a. Externally regulated system
b. Pump-fed system

8. TECHNICAL PROBLEMS:

LF_2 handling; lightweight, high-performance thrust chamber; materials compatability; thermal control.

9. POTENTIAL ALTERNATIVES:

Stay with current propellants

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

If current plans come to fruition and NASA increase the level of support, a flightweight, blowdown propulsion system will be available by 1980. Without NASA resources, this technology will not advance.

EXPECTED UNPERTURBED LEVEL 3

11. RELATED TECHNOLOGY REQUIREMENTS:

None

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. I-A-1a

1. TECHNOLOGY REQUIREMENT (TITLE): F_2/N_2H_4 S/C Propulsion Subsystem

PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis & Design																			
2. Component Dev.																			
3. Assembly																			
4. Test																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)							+												
3. Operations										*									
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE						▽											
NUMBER OF LAUNCHES										▽	First Mission		Potential Use				

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)b

1. TECHNOLOGY REQUIREMENT (TITLE): Long-Life Hydrazine Technology PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Increase the life of current hydrazine thrusters

4. CURRENT STATE OF ART: Hydrazine systems are "flying" today but not to the new demanding duty cycles.

HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

As missions become longer in duration and require more massive payloads, it becomes imperative to increase the understanding of the physical parameters which now potentially limit the life of hydrazine thruster catalyst poisoning by impurities in the propellant; large number of pulses; variation in catalyst loading methods and mechanical/retainer/preloading design; catalyst activity; catalyst breakup, all are typical of the problems that limit the life of a hydrazine thrusters. The technology needs to be extended so that it ensures a long-life, reliable thruster.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Flyby missions of the outer planets demand long-life and hence drive this technology.
b. Applicable to missions M1,4, 5.
c. Provide for higher reliability and long-life.
d. In order to demonstrate long-life, it will be necessary to run a ground based test effort.

TO BE CARRIED TO LEVEL 9&10

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A(1)b

1. TECHNOLOGY REQUIREMENT(TITLE): Long-Life Hydrazine Technology PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Heat catalyst bed; purify propellant

8. TECHNICAL PROBLEMS:

The catalyst bed is the problem.

9. POTENTIAL ALTERNATIVES:

Seek out other systems at risk of increasing mass and decreasing reliability.
Cold gas; small bipropellant systems, momentum wheels.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

There are no planned programs to increase thruster life.
Without NASA resources, the technology will not advance.

EXPECTED UNPERTURBED LEVEL 2

11. RELATED TECHNOLOGY REQUIREMENTS:

None

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. I-A(1)b

1. TECHNOLOGY REQUIREMENT (TITLE): Long-Life Hydrazine Technology

PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design			—	—															
2. Testing			—	—	—														
3. Design Refinement						—													
4. Testing						—	—	—											
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)c

1. TECHNOLOGY REQUIREMENT (TITLE): Long-Life Earth Storable Bipropellant Technology PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Increase the life and performance of earth-storable bipropellant propulsion system

4. CURRENT STATE OF ART: Earth-storable bipropellant systems are "flying" today, but mission of the future will, in all probability, push them up against the "today" technology. HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

Systems studies will be initiated to identify items that limit the life of the propulsion system. Redesign of these items, which in all probability include the soft-seat valve and current design materials, will take place. Engine technology will be undertaken to permit the use of N_2H_4 as a fuel in a bipropellant engine. After testing at the component level, a system will be assembled and tested to verify design adequacy, determine subsystem interaction, and most importantly, technology readiness.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Missions to the outer planets is the driving technology
b. Mission A1, 4, 5 would benefit from this technology
c. This technology would improve reliability and/or lifetime
d. Ground verification tests

TO BE CARRIED TO LEVEL 9&10

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)c

1. TECHNOLOGY REQUIREMENT(TITLE): Long-Life Earth - Storable Bipropellant Technology PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

None

8. TECHNICAL PROBLEMS:

Thrust chamber materials and combustion instability

9. POTENTIAL ALTERNATIVES:

Leave alone and accept the risks and lower performance and flexibility of currently used earth-storable propulsion systems.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

There are no planned programs and without NASA resources, the technology would not advance.

EXPECTED UNPERTURBED LEVEL 3

11. RELATED TECHNOLOGY REQUIREMENTS:

None

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. I-A-(1)c

1. TECHNOLOGY REQUIREMENT (TITLE): Long-Life Earth - Storable Bipropellant Technology

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis & Design																			
2. Component Dev.																			
3. Assembly Test																			
4. System Test																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)d

1. TECHNOLOGY REQUIREMENT (TITLE): Advanced Launch-Vehicle Engines Using High Density Fuel and Oxidizer Propellants PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Conduct the technology needed to permit the development of high performance, high pressure, (4000 Pc) reusable rocket engines using high density fuel and oxidizer propellants.

4. CURRENT STATE OF ART: Technology for high density fuel (hydrocarbon and amine) and liquid oxygen propellant combinations has been carried only to moderate pressures (1000 psi) HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

The technology needed includes a survey and characterization of promising hydrocarbon fuels that offer higher density-impulse than RP-1 with LOX, the acquisition of heat transfer data and thermal decomposition data, techniques for regenerative cooling with liquid oxygen, improved modeling of the combustion process and chamber gas dynamics at high pressure so that combustion instability can be avoided and energy release efficiency (performance) maximized, a search for high temperature resistant materials so that turbine temperatures can be raised and/or low cycle fatigue life extended, and development of composite or filament wound components and interconnects to minimize engine weight. Finally, engine system studies are needed to evaluate performance, engine weight, cooling limits, variations in the engine cycle, boost pump drive techniques, and development risk.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. The requirement for a high density propellant, high performance, high pressure engine is based on analyses which have been performed for a single-state-to-orbit vehicle concept. The critical parameters which drive the technology are high density impulse at lift-off and high stage mass fraction.
b. This advanced engine is part of a system which will enhance the Earth to Low-Earth-Orbit transportation capability by reducing recurring cost and possibly improving reliability.
c. Advances in high density propellant engine technology may enable the development of single-state-to-orbit launch vehicles, thus reducing recurring launch costs over two-stage systems.
d. Component and major subsystems tests (with subscale hardware as a minimum) are needed to demonstrate technology readiness.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)d

1. TECHNOLOGY REQUIREMENT(TITLE): Advanced Launch Vehicle Engines Using High Density Fuel and Oxidizer Propellants PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

None

8. TECHNICAL PROBLEMS:

Oxide coating on the coolant side of the combustor wall and/or unacceptable wall damage from small leaks may prevent cooling with oxidizer. Combustion stability comprimizes that may be required with some of the as yet uncharacterized hydrocarbon fuels may prevent obtaining sufficient performance.

9. POTENTIAL ALTERNATIVES:

None

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Survey of potential high density fuels currently underway, RTOP 506-21-xx. Investigation of supercritical oxidizer cooling currently underway, RTOP 506-21-11. High density fuel engine study currently underway, RTOP 506-21-xx. The proposed advancement would not occur without NASA resources. The state-of-the-art as described in item 4 would not change.

EXPECTED UNPERTURBED LEVEL 2

11. RELATED TECHNOLOGY REQUIREMENTS:

Materials research for higher temperature turbine and combustor materials.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. I-A-(1)d

1. TECHNOLOGY REQUIREMENT (TITLE): Advanced Launch Vehicle Engines Using High Density Fuel and Oxidizer Propellants

PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Propellant Characterization	—	—	—	—															
2. Heat Transfer & Cooling			—	—															
3. Combustion & Performance			—	—															
4. High Temperature Materials		—	—	—	—	—													
5. Engine Study					—	—													
APPLICATION																			
1. Design (Ph. C)							—	—											
2. Devl/Fab (Ph. D)									—	—	—	—	—	—					
3. Operations															—	—	—	—	—
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE						***											
NUMBER OF LAUNCHES																	

14. REFERENCES:

Gregory, John W., "Propulsion Technology needs for Advanced Space Transportation Systems." AIAA/SAE 11th. Propulsion Conference, Anaheim, CA, Oct. 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)e

1. TECHNOLOGY REQUIREMENT (TITLE): Advanced Launch Vehicle Engines Using Hydrogen and Oxygen Propellants PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Improve the technology now being used in the development of high performance, high pressure, reusable rocket engines using hydrogen and oxygen propellants.

4. CURRENT STATE OF ART: Technology currently exists and is being used for the development of a high performance, high pressure H_2-O_2 engine (SSME).

HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

The technology is needed for the future uprating of the current Space Shuttle Main Engine (SSME) and development of a high performance engine for a single-stage-to-orbit vehicle, and/or a heavy-lift vehicle. The technology is also applicable to a dual-fuel engine for a single-stage-to-orbit vehicle.

The technology improvements needed are materials research to permit increased turbine temperature and extended low cycle fatigue life for combustor components, extendible nozzles to better optimize performance, improved long life bearings and seals, and development of composite or filament wound components and interconnects to reduce engine weight.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. The requirement for high performance, high mass fraction, reusable stages for the Shuttle, and future single-stage-to-orbit and heavy life vehicles has been established.

   The technology for propulsion system improvement for these vehicles falls into three broad catagories: performance improvement, weight reduction, and longer lifetime. Performance can be increased by raising chamber pressure (and area ratio) and by use of of two-position nozzle. This implies increased turbine inlet temperature which is now limited by materials; a translatable nozzle skirt and materials research to reduce engine weight and provide longer life.

b. Technology is applicable to SSME performance improvement, weight reduction, and life extension and to the development of advanced hydrogen-oxygen and/or dual-fuel engines for single-stage-to-orbit or heavy lift vehicles.

c. Advances in hydrogen-oxygen propulsion technology will result in payload enhancement and reduced recurring cost through extended engine life.

d. Major subsystems testing is needed to demonstrate technology advancement.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)e

1. TECHNOLOGY REQUIREMENT(TITLE): Advanced Launch Vehicle Engines Using Hydrogen and Oxygen Propellants

7. TECHNOLOGY OPTIONS:

An option to developing higher temperature resistant materials for turbines is to devise viable turbine blade cooling techniques.

8. TECHNICAL PROBLEMS:

Development of higher temperature materials for turbine or turbine blade cooling techniques are major obstacles to improving specific impulse of staged combustion cycle engines.

9. POTENTIAL ALTERNATIVES:

None.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Thrust chamber heat transfer and cooling currently underway. RTOPS 506-21-11 and 790-40-12. The proposed advances would not occur without NASA sponsorship. The state-of-the-art as described in item 4 would not change.

EXPECTED UNPERTURBED LEVEL 2

11. RELATED TECHNOLOGY REQUIREMENTS:

Significant improvement in performance for staged combustion cycles is dependent upon development of higher temperature turbine materials or viable turbine blade cooling techniques.

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Advanced Launch Vehicle Engines Using Hydrogen and Oxygen Propellants. PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Thrust Chamber Cooling & Performance Predict.																			
2. Turbomachinery																			
3. Extendible Nozzle																			
4. Aerospike Sys. Demon.																			
5. ASE Sys. Demon.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE					X*						X**						TOTAL
NUMBER OF LAUNCHES																	

14 REFERENCES:

*SSME Uprating **Single-stage-to-orbit heavy lift vehicle

Gregory, John W., "Propulsion Technology Needs For Advanced Space Transportation Systems", AIAA/SAE 11th. Propulsion Conference, Anaheim, CA, Oct. 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)f

1. TECHNOLOGY REQUIREMENT (TITLE): Densification of Cryogenic Propellants By Use of Slush or Triple Point Fluid PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: 14 Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: (a) Produce triple point and/or two phase solid-liquid (slush) LH_2 and LO_2 (b). Establish ground based transfer and loading capability.

4. CURRENT STATE OF ART: The feasibility of using the freeze-thaw process to produce solid H_2 has been evaluated.

HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

Perform trade-off studies of various vehicles to determine benefits to be obtained by use of slush or triple point cryogens and utilize results to guide experimental work. Establish the techniques for producing, transferring, loading, and storing high density cryogenic propellants in ground based facilities. Maximum density increases can be obtained only through improvements in handling procedures and hardware that significantly reduce system heat losses.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Future launch and space vehicles can benefit by increasing propellant density. Substantial increases in stage ΔV occur by loading more propellant into a constant volume vehicle, such as stages constrained by the shuttle cargo by size.

The technology must be advanced to the point that mixtures of solid-liquid hydrogen in excess of 30% by weight solid can be reliablv loaded and maintained in a launch vehicle during the launch count-down procedure. This is also required in the case of triple point oxygen.

The use of slush or triple point cryogen also assists in storage of the cryogen in space for longer periods without excessive boil-off.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)f

1. TECHNOLOGY REQUIREMENT(TITLE): Densification of Cryogenic Propellants By Use of Slush or Triple Point Fluid PAGE 2 OF 3

7. TECHNOLOGY [illegible] TIONS:

8. TECHNICAL PROBLEMS:

Principal problems are related to manufacture, storage, and transfer of slush or triple point cryogen. The cryogenic system must be carefully designed to prevent heat leak into the system.

9. POTENTIAL ALTERNATIVES:

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

There are no programs in NASA currently directed at this problem.

EXPECTED UNPERTURBED LEVEL 3

11. RELATED TECHNOLOGY REQUIREMENTS:

High density hydrocarbon propellant manufacturing and characterization.

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. I-A-(1)f

1. TECHNOLOGY REQUIREMENT (TITLE): Densification of Cryogenic Propellants By Use of Slush or Triple Point Fluid — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. System Definition																			
2. Hardware Design																			
3. Test Demonstration																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

Suggested new category under 1.0 Low Cost Earth-to-Orbit Transporation in "Space Experiment Opportunities to Support the Outlook for Space Technology Recommendations"

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)g

1. TECHNOLOGY REQUIREMENT (TITLE): High Chamber Pressure H_2/O_2 Space Engines PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: High performance, light weight compact sized engines for advanced space vehicles through increase of chamber pressure to 2000 psia.

4. CURRENT STATE OF ART: Component development in progress, including main turbopumps, preburner, thrust chamber assembly engine preliminary design and boost pump drive.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

Technology program has been in progress at the Lewis Research Center since 1972 to develop technology for high performance hydrogen-oxygen engines suitable for advanced space vehicles, such as Space Tug. Efforts are aimed primarily at staged combustion cycle engine (ASE) of 20,000 pounds thrust but program also includes aerospike thrust chamber program previously funded by Air Force. Basic component technology on turbopump bearings and seals, injector design, thrust chamber cooling and chamber cooling and chamber thermal fatigue life is also applicable to other types of engines in this thrust class, such as expander cycle engines. Work to be carried through systems level testing of breadboard engines.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

(a) Chamber pressure increase to 2000 psia for staged combustion engine or 1000 psia for aerospike or expander/bell engine necessary to provide high specific impulse with minimum engine size and weight. Large expansion ratio nozzles are necessary to obtain high Isp and these become bulky and heavy at low chamber pressure.

(b) Engines applicable to upper stages like Centaur, IUS, Space Tug, and future vehicles for transfer from low earth orbit to geosynchronous orbit, to the moon or to escape velocity. Also applicable to vehicles for lunar landing and/or takeoff.

(c) See Page 4.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)g

1. TECHNOLOGY REQUIREMENT(TITLE): High Chamber Pressure H_2/O_2 Space Engines PAGE 2 OF 4

7. TECHNOLOGY OPTIONS:

An option to the use of a two position nozzle on the ASE is to pivot or swing the entire engine 90° for stowage in the shuttle cargo bay. This would reduce the stowed stage length by about two feet. An option to the aerospike is a plug cluster nozzle arrangement using a multitude of discrete, round-throat chambers exhausting onto a central plug nozzle. This gives a very short engine length and could make use of Shuttle APS thruster H_2/O_2 technology.

8. TECHNICAL PROBLEMS:

For small staged combustion engines the primary technology problems are chamber life, turbopump bearings and seals life, turbopump fabrication and system control. For the aerospike engine the primary technology problems are thrust chamber integrity and life.

9. POTENTIAL ALTERNATIVES:

The alternative to using an advanced engine is to use a lower performance, existing state-of-the-art engine. For the Space Tug the alternative to using the ASE or aerospike is to use the RL10 cat. IIB, a modified existing engine which operates at 400 psia chamber pressure and consequently delivers lower Isp and is larger and heavier than the advanced engines.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP 506-21-11 "Advanced Liquid Rocket Systems Technology"
RTOP 910-83-03 "Advanced H_2/O_2 Engine Component Technology"

Unperturbed Program - technology will not advance without NASA resources

EXPECTED UNPERTURBED LEVEL 4

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. I-A-(1)g

1. TECHNOLOGY REQUIREMENT (TITLE): High Chamber Pressure H_2/O_2 Space Engines PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Component Technology	—	—	—																
2. Breadboard Engine Program		—	—	—	—														
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)					—	(C	/	D)	—										
2. Devl/Fab (Ph. D)																			
3. Operations										—	—	—	—	—	—	—	—	>	
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE			Δ														
NUMBER OF LAUNCHES																	

14. REFERENCES:

1) Zachary, A.T.: Advanced Space Engine Technology, 1974 JANNAF Propulsion Meeting, San Diego, CA, Oct. 1974.

2) Huang, D.H.: Aerospike Engine Technology Demonstration for Space Propulsion, AIAA Paper No. 74-1080, AIAA/SAE 10th Propulsion Conference, San Diego, CA, Oct. 1974.

3) Gregory, J.W.: Propulsion Technology Needs for Advanced Space Transportation Systems, AIAA/SAE 11th Propulsion Conference, Anaheim, CA, Oct. 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

1. TECHNOLOGY REQUIREMENT (TITLE): High Chamber Pressure H_2/O_2 Space Engines

6. (c) The Space Tug is very sensitive to specific impulse and mass fraction because of the high ΔV it must provide. The ASE will provide about 15 seconds higher Isp than the RL10 category IIB and will be about 75 pounds lighter in weight. Overall stage length is also very important for the tug. The ASE with a two-position nozzle is about 16" shorter than the RL10 IIB and the aerospike engine is about 47" shorter than the RL10 IIB. Also, the ASE will provide 10 hours life as compared to 5 hours life for the RL10 IIB.

(d) Systems level testing of breadboard engines is needed to obtain data on component interactions, control requirements, and overall system performance. It will also provide a convincing demonstration of the overall technical maturity of the technology.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)h

1 TECHNOLOGY REQUIREMENT (TITLE): Tank Head Idle and Extendible Nozzle for Low to Moderate Chamber Pressure Hydrogen-Oxygen Space Engines PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide the technology for increasing the performance of low to moderate chamber pressure, bell nozzle, cryogenic space engines.

4. CURRENT STATE OF ART: Most of the technology is in hand; however idle mode operation and performance of extendible, high area ratio nozzles have not been demonstrated. HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

Tank head idle mode operation makes propulsive use of the propellant used for engine chilldown prior to restart after long coast periods. Previous tank head idle work resulted in unacceptable mixture ratio and chamber pressure excursions due to the injection of two-phase oxygen into the combustor. The plan is to control these excursions by vaporizing the oxygen in a hydrogen-oxygen heat exchanger prior to injection, thus avoiding the need for a closed loop engine control system.

Maximum performance of a space engine operating in a hard vacuum can be obtained only with large area ratio nozzles. Because these nozzles are necessarily long, they must be built in two parts for stowing in the Shuttle cargo bay. Therefore, the technology is needed to analyze, select, and demonstrate the minimum weight nozzle design, translating mechanism, hot gas seal and coolant connect and disconnect.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. High area ratio nozzles are required to maximize the performance of space engines operating in hard vacuum. Tank head idle mode reduces vehicle weight.

b. Engines for upper stage vehicles operating in space.

c. The payload requirements for the Space Tug require maximizing performance and mass fraction. This is obtained by optimizing the nozzle area ratio on the basis of specific impulse and nozzle weight, and making propulsive use of chilldown propellants by idle mode oepration.

d. System level testing of a flight weight extendible nozzle to demonstrate performance, nozzle translation and idle mode operation.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. I-A-(1)i

1. TECHNOLOGY REQUIREMENT(TITLE): Tank Head Idle and Extendible Nozzle for Low to Moderate Chamber Pressure Hydrogen-Oxygen Space Engines — PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Other nozzles options for attaining maximum performance consistent with the chamber pressure are aerospike and plug nozzles.

The proposed method for tank head idle operation is to vaporize the oxygen prior to injection under tank head and use an open loop engine control system. An option is to use a closed loop engine control system with mixed phase oxygen injection.

8. TECHNICAL PROBLEMS:

Distortion of a light, flight-weight nozzle during repeated thermal cycling may cause alignment, translation and sealing problems.

9. POTENTIAL ALTERNATIVES:

One piece nozzles could be used, resulting in a drastic reduction in payload length on Shuttle flights. Settling rockets or APS thrusters could be used in place of tank head idle but with an attendant weight penalty.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Heat exchanger design for vaporizing liquid oxygen in progress, NAS 8-31151, $155 K. The proposed advancement would not occur without NASA resources. The state-of-the-art as described in item 4 would not change.

EXPECTED UNPERTURBED LEVEL 2

11. RELATED TECHNOLOGY REQUIREMENTS:

None.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)h

1. TECHNOLOGY REQUIREMENT (TITLE): Tank Head Idle and Extendible Nozzle for Low to Moderate Chamber Pressure, Hydrogen-Oxygen Space Engines PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Tank head idle heat exch.																			
2. Nozzle anal.;des. & fab.																			
3. Nozzle & tank head idle demon.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE					X													
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)1

1. TECHNOLOGY REQUIREMENT (TITLE): Small H_2/O_2 Main and Auxiliary Propulsion Systems PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Small high performance H_2/O_2 engines and systems for attitude control, apogee kick stages, and planetary retro stages.

4. CURRENT STATE OF ART: 1500 pound thrust H_2/O_2 APS thrusters have been extensively tested for performance and life; APS system design and trade-off study completed for LH2/LOX APS system for tug. HAS BEEN CARRIED TO LEVEL 3&4

5. DESCRIPTION OF TECHNOLOGY

1. Development of technology for LH2/LOX APS system for tug including 25 pound thrust engines, small cryogenic pumps, accumulators, controls, and refillable tanks. After component technology is completed, systems testing will be performed to evaluate control requirement and measure heat input effects to thrusters and feed lines.

2. Develop technology for small thrust cryogenic engines of 300-3000 pounds thrust suitable for use on apogee kick stages and planetary retro stages. Perform vehicle/propulsion system studies to guide technology program and complete system preliminary design.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

(a) Small thrust cryogenic engines must be specially designed for accurate thermal control so that rapid start-up is achieved with cryogenic propellants entering a warm engine. For tug attitude control, impulse bits of about 1.0 lb-secs. are required, which necessitates rapid thrust build-up and tail-off. Long life is also necessary since the thrusters must be capable of 200,000 firings. For small kick stage or planetary retro stages the primary emphasis is on high performance, light weight, and reliability.

(b) For attitude control of space vehicles, such as space tug, or larger orbit transfer vehicles or lunar vehicles. Main propulsion engines for apogee kick stages or planetary retro stages.

(c) See Page 4.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)i

1. TECHNOLOGY REQUIREMENT(TITLE): Small H_2/O_2 Main and Auxiliary Propulsion Systems

7. TECHNOLOGY OPTIONS:

Principal option in cryogenic APS for tug involves degree of integration with other on-board systems, such as H_2/O_2 fuel cell supply system, and use of separate, dedicated tanks for the APS propellant, main tank, propellants, or refillable tanks. Systems study done by Rockwell under Lewis' contract NAS3-18913 showed that use of refillable tanks (from main tank propellants) results in the best system design.

8. TECHNICAL PROBLEMS:

Development of high performance, fast response, long life light weight thrusters, small cryogenic pumps, accumulators, and controls. Evaluation of system level control problems and effects of heat input into various components and parts of the system.

9. POTENTIAL ALTERNATIVES:

Alternative to use of cryogenic APS for Tug is use of earth storable or monoprop-hydrazine systems with their poorer performance, greater weight, and life and handling problems. For apogee kick stages, alternatives are solid propellants or higher bulk density liquid propellants.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP 506-21-11, "Advanced Liquid Rocket Systems Technology"
Unperturbed Program - Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 3&4

11. RELATED TECHNOLOGY REQUIREMENTS:

Long term cryogenic propellant storage; lightweight composite, vacuum-jacketed feed lines.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. I-A-(1)i

1. TECHNOLOGY REQUIREMENT (TITLE): Small H_2/O_2 Main and Auxiliary Propulsion Systems — PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design	—																		
2. Fabrication		—	—																
3. Component Test		—	—	—	—														
4. Systems Test							—												
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE						Δ												
NUMBER OF LAUNCHES																		

14. REFERENCES:

(1) Nichols, J. "Cryogenic Auxiliary Propulsion System Study for the Space Tug"; NASA CR-13479, June 1975, Lewis Contract, No. NAS3-18913.

(2) Gregory, J.W. and Herr, P.N.: "Hydrogen-Oxygen APS Thruster Technology Status:, AIAA/SAE 8th Propulsion Conference, New Orleans, LA; Nov. 1972.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)i

1. TECHNOLOGY REQUIREMENT (TITLE): Small H_2/O_2 Main and Auxiliary Propulsion Systems PAGE 4 OF 4

6. (c) LH2/LO2 Attitude control system for tug provides a lighter weight system than earth storables or monoprop. hydrazine. It also provides improved abort capability for Tug, since main propellants can be burned in the APS; clean, non-toxic, non-polluting propellants with inherent long life potential; reduction of main engine critical requirements such as tank head idle and pumped idle by using the APS for maneuvers. Use of cryogenic systems for kick stages or planetary retro stages provides higher payload capability and greater operational flexibility than solid rocket motors.

(d) Systems level testing in a thermal/vacuum facility needed for small cryogenic propulsion systems in order to evaluate effects of typical heat inputs to the system from the stage and the environment.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)j

1. TECHNOLOGY REQUIREMENT (TITLE): High Performance Space Engines Using High-Density Propellants PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: High performance, light weight compact sized engines for advanced space vehicles through increase of chamber pressure and use of high density propellants.

4. CURRENT STATE OF ART: Studies and analyses underway to evaluate applications for high performance space engines using high bulk density propellants. HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

Development of rocket engine technology for engines in the 5,000 to 30,000 pound thrust class that utilize high performance, high bulk density propellants, such as LOX-hydrocarbons, LOX-amine fuels, F_2/H_2, and N_2O_4/N_2H_4. Technology will also include dual fuel engines that are capable of utilizing a high density propellant combination, such as LOX-MMH during the early portion of a mission and switching to LOX-LH_2 later in the flight. Both bell and plug nozzle engines will be investigated. Experimental work will be preceded by application studies of various high bulk density propellant systems to select the most promising ones.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

(a) Increase of chamber pressure to 1000 psia or higher and use of pump-fed engines provides higher specific impulse with minimum engine size and weight. Large expansion ratio nozzles are necessary to obtain high Isp and these become bulky and heavy at low chamber pressure. Use of dual fuel system for Space Tug (or similar future vehicles) provides performance comparable to H_2/O_2 and a considerable reduction in stage size.

(b) Suitable for application to: space maneuvering reduction in stage size. Shuttle OME; vehicles for transporting payloads from low earth orbit to geosynchronous orbit or escape velocity such as Space Tug; and for lunar landing and takeoff vehicles.

(c) See Page 4.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)j

1. TECHNOLOGY REQUIREMENT(TITLE): High Performance Space Engines Using High-Density Propellants PAGE 2 OF 4

7. TECHNOLOGY OPTIONS:

The choice of propellant from among the options available will have considerable bearing on the technology needs and the engine design. A range of heavy hydrocarbons are applicable and they vary in density, impulse, cost, and basic properties. The amine fuel family offers a range of candidates with similar attributes. The flourine-hydrogen propellant combination is also a candidate for these applications.

8. TECHNICAL PROBLEMS:

Principal problem areas are engine cooling, combustion performance and stability, turbomachinery, component life, and engine controls. For dual fuel systems, the above problems apply plus additional problems related to use of two fuels alternately in the same engine, such as injector design and hot gas manifold shutoff valves.

9. POTENTIAL ALTERNATIVES:

The alternative to developing new high performance space engines for high bulk density propellants is to continue using low pressure, low-performance engines and earth storable propellants (N_2O_4 - MMH or A50) which have considerable problems associated with toxicity, handling, reusability, and cost.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Unperturbed program - Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 2

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. I-A-(1)j

1. TECHNOLOGY REQUIREMENT (TITLE): High Performance Space Engines Using High-Density Propellants — PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	
TECHNOLOGY																		
1. Analysis/Design	—	—																
2. Fabrication		—	—	—														
3. Component Test				—	—	—	—											
4. Systems Test						—	—											
5.																		
APPLICATION																		
1. Design (Ph. C)																		
2. Devl/Fab (Ph. D)																		
3. Operations																		
4.																		

(CALENDAR YEAR)

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE							Δ								TOTAL
NUMBER OF LAUNCHES															

14. REFERENCES:

(1) Salkeld, R. and Beichel, R.: "Mixed Mode Propulsion Systems for Full Capability Space Tugs", 21st Annual Meeting American Astronautical Society, Denver, Colo., Aug. 1975.

(2) Dandridge, M.H.: "LOX/MMH Propulsion for Space Tug", 1974 JANNAF Propulsion Meeting, San Diego, CA, Oct. 1974.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL

DEFINITION OF TECHNOLOGY REQUIREMENT

1. TECHNOLOGY REQUIREMENT (TITLE): High Performance Space Engines Using High-Density Propellants

NO. I-A-(1)j

6. (c) Present high bulk density propellant systems typically use earth storable propellants (N_2O_4 - MMH or A50 fuel) and low performance (about 300 secs. Isp), low pressure engines. Significant gains in system performance may be achieved by utilizing higher performance, high bulk density propellants, such as LOX-hydrocarbon or LOX-amine fuel, and developing suitable higher pressure, pump-fed engines utilizing such propellants. System weight will be reduced, and in the case of dual fuel systems, the system volume will be significantly reduced compared to an all H_2/O_2 system. Propellant cost will also be reduced in some cases; for example, switching from N_2O_4 - MMH to LOX-hydrocarbon for the Shuttle OMS could save up to $100K per flight.

(d) Systems level testing of breadboard engines will eventually be required to fully demonstrate technology readiness.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)k

1. TECHNOLOGY REQUIREMENT (TITLE): Low-cost Liquid Booster Engines PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide the technology needed to develop low cost, low to intermediate pressure, pressure-fed or pump-fed, large thrust engines.

4. CURRENT STATE OF ART: Technology for low chamber pressure engines is limited to low thrust, small diameter engines.

HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

The technology needed includes development of techniques for the design of large diameter, minimum weight nozzles, combustors and other components that can withstand the water landing loads, the manufacture and fabrication of these large assemblies, sealing the engine compartment prior to landing to prevent water contamination, flushing, cleaning, and refurbishing the system (particularly for pump-fed systems) should sealing the engine compartment not be feasible. The use of high strength, low weight composite or filament would combustion chambers and nozzles must be investigated. The combustion stability characteristics of the system must be determined from analytical models, and injector orifice elements and patterns must be experimentally investigated to insure that combustion characteristics compatible with the gas dynamics of very large diameter, low resonant frequency combustors are produced.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Low-cost, low to moderate chamber pressure (200-1000Pc) engines operating on inexpensive liquid propellants, could have a near term application as a replacement for the solid rocket motors on the Space Shuttle, thus reducing recurring propellant costs.

b. In the far term, low-cost, high thrust boosters would be used to augment the thrust of large, heavy life vehicles and/or early versions of single-stage-to-orbit vehicles.

c. Low-cost boosters represent a cost effective method of providing high thrust for large launch vehicles.

d. Systems level testing using subsclae hardware is needed.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. I-A-(1)k

1. TECHNOLOGY REQUIREMENT(TITLE): Low-cost Liquid Booster Engines — PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

None.

8. TECHNICAL PROBLEMS:

Difficult and costly to work with large size hardware. Results obtained with subscale hardware may not apply to the full scale system. Problems associated with components and systems such as low and high frequency combustion instability, large, low pressure drop valves, large, light weight components and propellant tanks and large flow rate pressurization systems.

9. POTENTIAL ALTERNATIVES:

None.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

The proposed advancement would not occur without NASA sponsorship. The state-of-the-art described in item 4 would not change.

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

None.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. I-A-(1)k

1. TECHNOLOGY REQUIREMENT (TITLE): Low-cost Liquid Booster Engines　　PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Materials Investment																			
2. Design & Fab. Tech.																			
3. Water Recovery & Refurb. Techniques																			
4. Combustion Stability Investigation																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE						X											
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. I-A-(1)k

1. TECHNOLOGY REQUIREMENT (TITLE): High Performance Cryogenic Insulation for Reusable Spacecraft — PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: 14 Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide a high performance insulation system for the propulsion system of a cryogenically fueled spacecraft that will maintain a consistent level of performance for a minumum of 20 missions.

4. CURRENT STATE OF ART: Single use purged multilayer insulation systems are available.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

Cryogenic fueled spacecraft that are expected to be subjected to a cyclic environment of launch, space flight, and re-entry require that a high performance insulation be developed that will provide reliable and consistent performance throughout the spacecrafts lifetime.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Failure to produce the level of performance and reliability required will result in increased mission costs and or loss of mission payload.

Perform sufficient component and model testing to assure adequate system performance.

Eventual system flight testing will be performed as part of the cryogenic supply and transfer experiment.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)k

1. TECHNOLOGY REQUIREMENT(TITLE): High Performance Cryogenic Insulation for Reusable Spacecraft

7. TECHNOLOGY OPTIONS:

(1) Also existing single use system and replace after each flight, which increases payload costs.

(2) Use existing single use system and accept performance degradation, which increases mission risks and increases costs.

8. TECHNICAL PROBLEMS:

Need adequate ground test facilities. Reduction in total spac. program has resulted in both contractor's and government facilities being closed.

9. POTENTIAL ALTERNATIVES:

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP 506-21-12 is directed to this need. However, loss of continued funding support will result in inability to fulfill this need.

Unperturbed Program - Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 4

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. I-A-(1)1

1. TECHNOLOGY REQUIREMENT (TITLE): High Performance Cryogenic Insulation for Reusable Spacecraft

PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Purge Evaluation																			
2. Comparative System																			
3. Total System Evaluation																			
4. Evaluation in Space																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE				4													
NUMBER OF LAUNCHES																	

14. REFERENCES:

"Outlook for Space"

1975 NASA OAST Summer Workshop

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)m

1. TECHNOLOGY REQUIREMENT (TITLE): Insulation for Reusable Hydrogen Tanks for Advanced Boosters PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: 14 Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide light weight, low cost insulation for reusable booster vehicle tankage.

4. CURRENT STATE OF ART: Insulations similar to that used on S-IV B stage have been evaluated for re-use applications.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

In support of the fully reusable 2-stage H-O shuttle concept first advanced in the early '70's, some technology work on internal insulation systems was performed. Now fully reusable, single stage to orbit (SSTO), and heavy lift launch vehicles are being advocated. The effort on insulation improvement should focus on low weight, low cost, maximum resistance to thermal cycling, and ease of repair.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

SSTO vehicles are both more weight sensitive and cost sensitive than the 2-stage concept. Therefore, the critical parameters for this technology are: weight, cost, ruggedness, and ease of repair.

This effort should build on the technology base already established with special attention given to new requirements. Full operational capabil'ty should be demonstrated.

TO BE CARRIED TO LEVEL 8

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)m

1. TECHNOLOGY REQUIREMENT(TITLE): Insulation for Reusable Hydrogen Tanks for Advanced Boosters

7. TECHNOLOGY OPTIONS:

8. TECHNICAL PROBLEMS:

9. POTENTIAL ALTERNATIVES:

Do nothing - suffer system performance losses and increased costs

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

No programs in NASA are currently directed at this problem

EXPECTED UNPERTURBED LEVEL 4

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. I-A-(1)m

1. TECHNOLOGY REQUIREMENT (TITLE): Insulation for Reusable Hydrogen Tanks Used in Earth to Orbit Boosters — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Materials Evaluation		—	—	—															
2. System Design				—	—														
3. Ground Test Eval.					—	—													
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

"Outlook for Space" - Technology Category 1.2 in "Space Experiment Opportunities to Support the Outlook for Space Technology Recommendations"

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)p

1. TECHNOLOGY REQUIREMENT (TITLE): Composite Engines Technology PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Composite (Rocket/Air Breathing Engines Technology for advanced HTOHL Shuttle-type vehicles.

4. CURRENT STATE OF ART: Ramjets of small size suitable for tactical missles have been developed; studies of composite engines have been done and subscale ejector ramjets tested by Marquardt. HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

Future horizontal takeoff-horizontal landing (HTOHL) shuttle-type vehicles require composite engines that operate as rockets for high thrust at take off and switch to air breathing engines (ramjet, scramjet, etc.) to obtain high specific impulse at higher altitudes. Considerable study effort is needed to investigate the various types of engine combinations, to investigate the vehicle concepts, and integration of the two. After selection of the engine type, technology work will be needed on engine components, engine performance modeling, subscale cold flow, and hot firing tests of a subscale or modular section of the engine.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

(a) Critical parameters are dependent upon engine type and thrust level selected as well as vehicle design constraints. Engine desgin must be closely integrated with the vehicle design to insure satisfactory air ingestion for the range of Mach numbers and vehicle incidence angles.

(b) Application is to the first stage of a two-stage-to-orbit fully reusable shuttle type HTOHL vehicle for transporting payloads from earth to low earth orbit.

(c) See page 4.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)p

1. TECHNOLOGY REQUIREMENT(TITLE): Composite Engines Technology PAGE 2 OF 4

7. TECHNOLOGY OPTIONS:

Many options in the realm of composite engine design, including (for example) ducted rocket, ejector ramjet, scramjet, air turborcket, LACE Cycles, and many others, Most of the concepts beyond the simplest ducted or air augmented rocket involve secondary combustion or large scale turbomachinery or both.

8. TECHNICAL PROBLEMS:

The technical problems are dependent upon the engine concept selected, but include, for example, engine cooling, afterburner design, and variable area inlet control.

9. POTENTIAL ALTERNATIVES:

Alternative approaches to the HTOHL concept are all rocket vehicles of one or two-stage-to-orbit design which generally have higher gross lift-off weight, higher propellant consumption, and higher launch cost per pound of payload.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Unperturbed program - technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 3

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. I-A-(1)P
1. TECHNOLOGY REQUIREMENT (TITLE): Composite Engines Technology	PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Vehicle/Propulsion System Analyses			—	—															
2. Engine System Studies					—	—	—												
3. Design/Fabrication						—	—	—											
4. Component Test							—	—	—	—									
5. Subscale Engine Test										—	—								
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	TOTAL
TECHNOLOGY NEED DATE											Δ						
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(1)p

1. TECHNOLOGY REQUIREMENT (TITLE): Composite Engines Technology

6\. (c) The HTOHL two-stage fully reusable shuttle vehicle offers advantages over other vehicle concepts in that it has very low recurring launch cost and low gross lift-off weight (GLOW) for a given payload capability. The HTOHL approach using composite engines in the first stage has been predicted to have launch costs of about $20/lb. for a 60,000 pound payload class vehicle.

(d) Vehicle/propulsion system analyses, engine concept selection, engine preliminary design, component development, engine system modeling, and subscale engine testing are needed to bring the technology to maturity.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(2)a

1. TECHNOLOGY REQUIREMENT (TITLE): Low-Cost Solid Rocket Booster Motor PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide technology which will decrease the cost of future solid rocket booster motors by 50%.

4. CURRENT STATE OF ART: The current cost of large solid rocket motors is $1.00-3.00 per kilogram.

HAS BEEN CARRIED TO LEVEL 1

5. DESCRIPTION OF TECHNOLOGY

The cost of a solid rocket motor is made up of many elements which can be changed in order to minimize the cost. There are three that have been identified: filament wound chambers, lower cost nozzle materials, and lower cost insulation. These will not be selected for development until they have been demonstrated for Shuttle SRM use. Others are: propellant binder, and other ingredients to decrease propellant costs, testing, quality control, and documentation as well as manufacturing methods and refurbishment. More specifically as examples: Tech-Roll-Seal TVC in place of Lockseal. Inspection of case segments after recovery for refurbishment. Insulation type and technique of application during refurbishment. Hydroxy terminated polybutadiene propellant binder instead of PBAA. Carbon/carbon nozzle components.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Substantial amounts can be saved considering the large traffic planned for Shuttle flights; the three areas selected for technology advancement have been completed except for demonstrating against SRB requirements.

b. Motors using this technology would be used for missions from earth to low earth orbit. M1

c. The actual cost decrease is not known, but would be determined in the first phase of the effort.

d. Each of these technology items must be demonstrated so that the risk is minimal to the project by a test program to demonstrate cost and performance.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(2)a

1. TECHNOLOGY REQUIREMENT(TITLE): Low-Cost Solid Rocket Booster Motor PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

This program would consider the value of making changes to the way SRB's are designed, manufactured, tested, inspected, documented, and refurbished. Where there is a lack of technology or risk needs to be reduced, demonstrations would be made.

8. TECHNICAL PROBLEMS:

9. POTENTIAL ALTERNATIVES:

Use current high cost techniques or develop low-cost liquid systems.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Shuttle SRB development has not planned for this technology requirement. Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 1

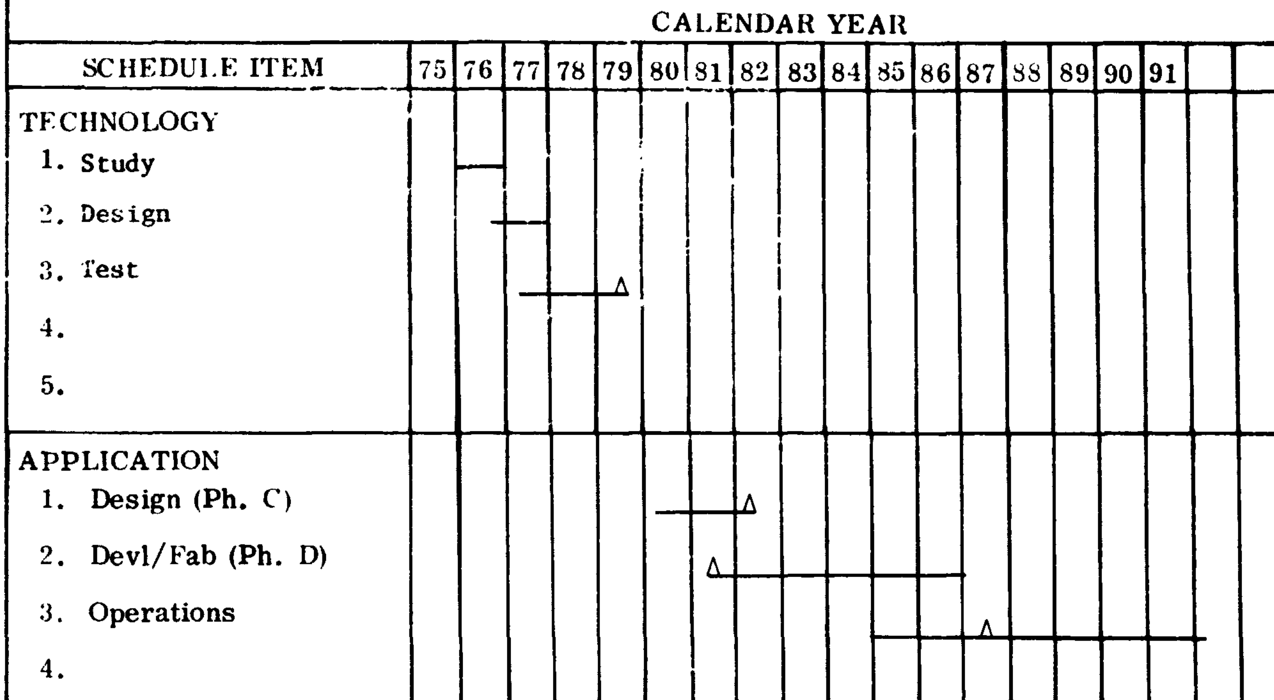
11. RELATED TECHNOLOGY REQUIREMENTS:

For minimum cost these low cost technologies should be part of the second buy of SRB's.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(2)a

1. TECHNOLOGY REQUIREMENT (TITLE): Low-Cost Solid Rocket Booster Motor PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:



13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE																	TOTAL
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(2)a

1. TECHNOLOGY REQUIREMENT (TITLE): High Performance Solid Kick Motors PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: To provide technology demonstration for high performance upper stages such as kick motors.

4. CURRENT STATE OF ART: NASA solid upper stage motors currently in use were developed in the early 1960's, and technology has advanced, but has not been completely demonstrated. HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

The motors now being used by NASA upper stages for maneuvers such as kick in-the-apogee were developed during early 1960's. New technology is available, which can be applied to improve the specific impulse, mass fraction, cost and interface requirements. Mass fraction can reasonably be expected to increase from 0.92 to 0.95 and specific impulse from 280 to 300 sec.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. For high energy planetary missions the current state-of-the-art requires full booster capability and limits the payload that escapes earth; a kick motor is needed with about 2000 kg. of propellant to provide the full Shuttle/IUS capability for high energy missions as well as large payloads to geosynchronous orbit.

b. These motors find application in transport from low earth orbit to geosynchronous orbit and interplanetary injection; A 3 and 4.

c. Some payloads for high energy missions cannot be delivered without a new kick stage motor.

d. The technology should be statically demonstrated in flight design hardware.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. I-A-(2)b

1. TECHNOLOGY REQUIREMENT(TITLE): High Performance Solid Kick Motors — PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

The IUS or Tug payload capability would be markedly improved by developing a 2000 to 10,000 kg motor and by taking advantage of higher performing insulation and case materials, propellants, and control techniques. A stop-restart motor can provide up to 50% more payload in orbit than a single-burn motor. A thrust vector control system needs to be selected from the several moveable nozzle options such as Tech-Roll-Seal, Lockseal, or Thiovec.

8. TECHNICAL PROBLEMS:

9. POTENTIAL ALTERNATIVES:

Liquid kick stages or use technology without benefit of demonstrations.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Portions of Prog. 1 (see schedule) are supported by RP, RTOP 506-21-32.
Program 2 (see schedule) has no planned support.
DOD programs; however, are class 7 propellants which are currently not allowed on the shuttle vehicle; thus, NASA requires a new high performance class 2 propellant.
Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 3

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(2)b

1. TECHNOLOGY REQUIREMENT (TITLE): High Performance Solid Kick Motors PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY Program1																			
1. Design																			
2. Fabrication																			
3. Testing																			
4. Demonstration																			
5.																			
TECHNOLOGY Program2																			
1. Design																			
2. Demonstration																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	TOTAL
TECHNOLOGY NEED DATE				X				X									
NUMBER OF LAUNCHES			PROGRAM			1	PROGRAM			2							

14. REFERENCES:

"Which Way to Shuttle Upper Stages?", A.O. Tischler, p.26-37, AIAA, A and A, Volume 13, No. 7, July/Aug., 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-A-(2)c

1. TECHNOLOGY REQUIREMENT (TITLE): High Performance Space Solid Motors PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide technology for solid propellant motors of high performance which can withstand the sterilization environment.

4. CURRENT STATE OF ART: Motor sizes up to 75 kg and mass fractions of 0.85 km have been achieved. Large sizes have not been demonstrated.

HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

Technology for motor sizes up to 300 kg and performance of 0.9 mass fraction will be developed to effectively provide propulsion for sample return from the planets.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. There is a large payoff in increased sample size return if the performance of the propulsion system is increased.

b. Extraterrestrial landing and take-off (in particular Mars sample return); M5

c. These missions operate at very large ratios of sample returned to mass landed, i.e., a 50 gram sample for a 3000 kg spacecraft launch.

d. Demonstration by static test in flight prototype hardware.

TO BE CARRIED TO LEVEL 5

1. TECHNOLOGY REQUIREMENT(TITLE): High Performance Space Solid Motors

7. TECHNOLOGY OPTIONS:

Conduct a demonstration program after increasing the performance and stability of the propellant system by increasing the solids loading from 81% to 85% to obtain an increase from 280 to 290 sec. The design of the motor is to capitalize on grain stress relief techniques. To complete the demonstration the motor needs to be designed, fabricated, subjected to thermal sterilization cycles and static tested.

8. TECHNICAL PROBLEMS:

Obtain thermally stable propellant and insulation systems in 300 kg sizes.

9. POTENTIAL ALTERNATIVES:

Use lower performing system: I_s of 250 sec. and mass fraction of 0.75.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Currently being investigated by JPL with support from RP.
RTOP 506-21-32. Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 2

11. RELATED TECHNOLOGY REQUIREMENTS:

None.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. I-A-(2)c

1. TECHNOLOGY REQUIREMENT (TITLE): High Performance Space Solid Motors — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Propellant	—	—	—																
2. Design			—																
3. Fabricate				—	—														
4. Dem^nstration Firing						Δ													
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE								Δ										
NUMBER OF LAUNCHES																		

14. REFERENCES:

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-B

1. TECHNOLOGY REQUIREMENT (TITLE): Metastable States of Matter PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Determine feasibility of utilizing metastable matter for propulsion and undertake an advanced hardware development program to demonstrate technology readiness.

4. CURRENT STATE OF ART: The metastable states of matter are currently under analysis and laboratory investigation.

HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

Currently the metastable states of matter under analytical and experimental investigation are metallic hydrogen, excited helium and mixtures of atomic and molecular hydrogen. The technology is in the conceptual or very early stages of experimental investigation. It is many years away from technology readiness, which is anticipated to be beyond the end of the century.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a) High-energy missions are very sensitive to specific impulse and therefore any improvement in that parameter has the potential of improving the mission.

b) This falls under the category of opportunity driven missions.

c) The payload will increase, to a zeorth order, directly as the log increase of Isp, therefore payloads will increase by orders of magnitude if system mass does not increase over current systems.

d) Too early to know.

TO BE CARRIED TO LEVEL 8

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. I-B

1. TECHNOLOGY REQUIREMENT(TITLE): Metastable States of Matter — PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

None.

8. TECHNICAL PROBLEMS:

Storage of matter in the metastable states at reasonable system mass; energy release at the proper point in the system; production of metallic hydrogen.

9. POTENTIAL ALTERNATIVES:

H_2/O_2 , F_2/N_2H_4 propellants (stable chemcials)

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

New Horizons Program at JPL.

Without NASA resources, the tecnnology will not advance.

EXPECTED UNPERTURBED LEVEL 2

11. RELATED TECHNOLOGY REQUIREMENTS:

None.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. I-B

1. TECHNOLOGY REQUIREMENT (TITLE): Metastable States of Matter   PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis and lab work																			
2. Evaluate Properties																			
3. System Studies																			
4. Critical Hardware Evaluation																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-C

1. TECHNOLOGY REQUIREMENT (TITLE): Utilization of Indigenous Materials for Propulsion PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop the technology for using the mass of extra-terrestrial surface material, planetary atmosphere and waste for propulsion.

4. CURRENT STATE OF ART: To date only mass taken from earth has been used by the NASA. It has been demonstrated that solid waste can be burned in a hybrid rocket.

HAS BEEN CARRIED TO LEVEL

5. DESCRIPTION OF TECHNOLOGY

Matter can be found in many forms and places where man will explore the solar system, and this material could be used for propellant mass; however; the form is usually not the same as found on earth.

New technology will be developed to convert indigenous mass to useful form, and to release energy when combined with stored constituents.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. New schemes need to be devised, concepts compared, tested, and technology developed.

b. These efforts are opportunity driven.

c. Currently all propellant mass must be brought from the earth with 70 to several thousand times that mass being expended to get the propellant mass into space. Thus the use of indigenous materials for propulsion can greatly reduce transportion system mass and cost for missions to distant planets and their satellites.

d. Concepts for reacting indigenous materials with stored reactants must be identified and their characteristics evaluated in order to determine if systems development is warranted.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-C

1. TECHNOLOGY REQUIREMENT(TITLE): Utilization of Indigenous Materials for Propulsion PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

The only option for not using indigenous mass is to carry the mass from earth. Within the indigenous materials there is a variety of options which are unknown at this time. The atmosphere of Venus is mostly CO_2 which could be reacted to form metal oxides plus heat, or just collected, heated, and expelled at higher velocity. Use of waste mass in a hybrid rocket for auxiliary propulsion has been demonstrated to be a technique which could be used on manned operations.

8. TECHNICAL PROBLEMS:

Energy, mass, and cost of using these systems when material has to be gathered.

9. POTENTIAL ALTERNATIVES:

Carry along mass from earth.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

New Horizons in Propulsion Program in RP
Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

Studies which will define specific missions and approaches.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. I-C

1. TECHNOLOGY REQUIREMENT (TITLE): Utilization of Indigenous Materials for Propulsion — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Study	---	---	---	---	---	---	---												
2. Selection of Approaches				---			---												
3. Laboratory Experiments				---	---	---	---	---	---	---									
4. Breadboard Systems								---	---	---	---	---							
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

CALENDAR YEAR

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-D

1. TECHNOLOGY REQUIREMENT (TITLE): Detonation Propulsion PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide prototype of mechanization of a detonation propulsion system which can be used in dense atmospheres.

4. CURRENT STATE OF ART: Feasibility has been shown for single pulses in laboratory apparatus.

HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

It has been bound that a small charge can be detcnated in an expanding nozzle and provide an impulse hwich to the first order is independent of atmosphere around the propulsion system.

The technology program consists of providing stable high energy detonable propellants which can be stored, transfered and ignited in the reactor; technology development of chamber refilling techniques, and transfer of the pulsed energy into the payload. Nozzle optimum design, prototype system design, and prototype system demonstration would complete the technology program.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. The results of estimates of current technology indicates that specific impulses of 50 to 150 sec. could be expected in dense, high-pressure (100-1000 bars) atmospheres while detonation propulsion should permit greater than 200 sec.

b. Extraterrestrial landing take-off and on orbit operations; M-1 and 5.

c. Should be able to decrease propellant mass by factor of 2.

d. Demonstration of a prototype unit in the laboratory.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-D

1. TECHNOLOGY REQUIREMENT(TITLE): Detonation Propulsion PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

The range of specific impulses varies from 200 to 300 sec. but depends on obtaining a propellant which can be packaged efficiently and initiated. The number of pulses varies from several hundred to a hundred thousand; the size of the change is one to twenty-five grams.

8. TECHNICAL PROBLEMS:

Obtain multiple pulse operation; transfer of pulse thrust into payload. Nozzle refilling between pulses. System to initiate propellant detonation; condidate approaches for ignition are: laser, shock wave, detonation wave, acoustic, resistance heating, broad spectrum heating.

9. POTENTIAL ALTERNATIVES:

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Currently being investigated at JPL under RP support. RTOP 506-21-32. Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 3

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO. I-D

1. TECHNOLOGY REQUIREMENT (TITLE): Detonation Propulsion PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Laboratory	--	--	--																
2. Design		--																	
3. Fabrication			--	--															
4. Test				--	--	--													
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. II-A-1(a)-1

1. TECHNOLOGY REQUIREMENT (TITLE): Nuclear Electric Propulsion Powerplant — PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Demonstrate, in a complete ground prototype test, a fast-spectrum, light weight, low cost, multi-hundred kWe technology for a space nuclear electric power subsystem for primary electric propulsion.

4. CURRENT STATE OF ART: Thermionic fuel elements for an in-core thermionic reactor were carried to EM design. Subsystem conceptual design was essentially completed in 1973. HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

The system to be designed and demonstrated is A-3-Mwt (or larger) heat pipe-cooled, fast reactor, operating at 1600K, utilizes Brayton, Sterling, Rankin, or thermionic power conversion. The prime contender presently is out-of-core thermionic power converters, at 15% to 25% conversion efficiency, to generate electrical power. Heat rejection, at 850°K, is via NaK coolant and heat pipe radiator structures. A large shadow shield (a metal hydride) is imposed between the reactor (with its assoicated power conversion) and the rest of the spacecraft neutron shielding. It is expected that the major part of the gamma shielding will be provided by the on-board propellant. Specific mass of the power subsystem is presently estimated at less than 20kg/kWe, designed for 30,000 hours of full power operation and a total lifetime of at least 90,000 hours.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. High energy planetary exploration at Jupiter, Saturn and the other planets is expected to start by the early 1990's. NEP will provide a low-cost, multi-payload, multi-mission spacecraft capability via the planned technology. In particular, lower specific mass, long life, and lower cost are accomplished by out-of-core power conversion at the specified temperatures.

b. Mission needs are interplanetary transport and on-orbit operation requirements of outer planet orbiters, satellite landers, and surface sample return missions. In addition, these subsystems are required for large payload transport from LEO to geosynchronous orbit or escape velocity.

c. NEP at Jupiter will provide approximately a factor of 3 larger payloads (on direct flight from a single STS launch) than a 3-stage chemical propulsion system from a dual STS launch via Venus swingby. This extra payload provides multiple orbiter/lander systems for the Jovian satellites and also enables a sample return flight to earth orbit, all with a single NEP system. Recurring cost for this NEP mission may also be lower than for the limited chemical system.

(Cont'd)

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. II-A-1(a)-1

1. TECHNOLOGY REQUIREMENT (TITLE): Nuclear Electric Propulsion Powerplant

(Continued)

6d. A ground prototype test is required, although it may also be desirable to have a short powered flight system test in space.

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. II-A-1(a)-1

1. TECHNOLOGY REQUIREMENT(TITLE): Nuclear Electric Propulsion Powerplant — PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Because of highly favorable payload/flight time tradeoff capability unique to NEP, this system is relatively insensitive to launch window and payload increases. Power available for mission equipment is virtually unlimited. System is expected to have 20% redundancy to cover power degradation over specified lifetime.

8. TECHNICAL PROBLEMS:

a. Heat pipe cooled reactor
b. Long life thermionic converter
c. HaK coolant manifolds
d. Heat pipe radiator structures
e. High temp. hydride neutron shield
f. High temp. cermet insulators
g. Sputter resistant coatings
h. Cabling and power processing
i. Spacecraft integradation
j. Ground test facilities

9. POTENTIAL ALTERNATIVES:

In-core thermionic reactor development, although a heavier and more costly technology, could also provide a major improvement over chemical systems.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Without special effort by NASA, this advancement would not occur.

EXPECTED UNPERTURBED LEVEL 3

11. RELATED TECHNOLOGY REQUIREMENTS:

This technology also requires the availability of a high power thrust subsystem technology to accomplish the stated missions. Other technologies are implied above in "Technical Problems" (item 8).

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. II-A-1(a)-1

1. TECHNOLOGY REQUIREMENT (TITLE): Nuclear Electric Propulsion Powerplant

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design			—	—	—	—	—												
2. Fabrication						—	—	—	—	—	—								
3. Test											—	—							
4. Documentation												—	—						
5.																			
APPLICATION																			
1. Design (Ph. C)													—						
2. Devl/Fab (Ph. D)														—	—				
3. Operations																—			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE													X					
NUMBER OF LAUNCHES																1	2	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. II-A-(1)(b)-2

1. TECHNOLOGY REQUIREMENT (TITLE): High Power Electrostatic Thrust Subsystem PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Demonstrate, in a complete ground prototype test, the technology for a multi-hundred kWe electrostatic thrust subsystem and its associated propellant storage and distribution subsystem for primary nuclear powered electric propulsion.

4. CURRENT STATE OF ART: Similar subsystems are currently under prototype development for solar electric propulsion at a power level of 5-30. kWe, scheduled for completion approx. 1980. HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

Design and demonstrate a 400 kWe power processor and a 300-mm ion bombardment, 3 axis control thrust array, with switching and logic for operation at an exhaust velocity up to 100 km/s. Heat pipe cooling of the array mounting platform will maintain temperature below 500K to assure active control of propellant flow. Specific mass of the thrust subsystem is presently estimated at less than 4 kg/kWe, designed for 30,000 hours of full power operation and a total lifetime of at least 90,000 hours.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. High energy planetary exploration at Jupiter, Saturn and the other outer planets is expected to start by the early 1990's. NEP will provide a low-cost, multi-payload, multi-mission spacecraft capability via the planned technology. In particular, lower specific mass, along life, and lower cost are accomplished by out-of-core power conversion at the specified temperatures.

b. Mission needs are interplanetary transport and on-orbit operation requirements of outer planet orbiters, satellite landers, and surface sample return missions. In addition, these subsystems are required for large payload transport from LEO to geosynchronous orbit or escape velocity.

c. NEP at Jupiter will provide approximately a factor of 3 larger payloads (on direct flight from a single STS launch) than a 3-stage chemical propulsion system from a dual STS launch via Venus swingby. This extra payload provides multiple orbiter/lander systems for the Jovian satellites and also enables a sample return flight to earth orbit, all with a single NEP system. Recurring cost for this NEP mission may also be lower than for the limited chemical system.

d. A ground prototype test is required, although it may also be desirable to have a short powered flight system test in space.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. II-A-(1)(b)-2

1. TECHNOLOGY REQUIREMENT(TITLE): High Power Electrostatic Thrust Subsystem PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Because of highly favorable payload/flight time tradeoff capability unique to NEP, this system is relatively insensitive to launch window and payload increases. Power available for mission equipment is virtually unlimited. Subsystem is expected to have 20% redundancy to cover performance degradation over specified lifetime.

8. TECHNICAL PROBLEMS:

a. Heat pipe cooling of structure
b. Propellant tankage to provide full gamma shielding
c. Interaction of exhaust with spacecraft structures and surfaces
d. Spacecraft integration
e. Ground test facilities

9. POTENTIAL ALTERNATIVES:

None

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Without special effort by NASA, this advancement would not occur.

EXPECTED UNPERTURBED LEVEL 3

11. RELATED TECHNOLOGY REQUIREMENTS:

This technology requires the availability of a nuclear power subsystem technology to accomplish the stated missions. It also requires further development of guidance and navigation technology for large, constant power, low thrust missions.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. II-A-(1)b

1. TECHNOLOGY REQUIREMENT (TITLE): High Power Electrostatic Thrust Subsystem

PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design																			
2. Fabrication																			
3. Test																			
4. Documentation																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																1	2	3

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. II-A-(1)(c)

1. TECHNOLOGY REQUIREMENT (TITLE): MPD Thrust Subsystem Technology — PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Demonstrate, in a complete ground prototype test, the technology for a multi-hundred kWe MPD arc jet subsystem and its associated propellant,storage and distribution subsystem for primary nuclear powered electric propulsion.

4. CURRENT STATE OF ART: Analytical and experimental research has been done in a quasi-steady magnetoplasmadynamic (MPD) discharge with a self-induced magnetic field and different propellants. HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

A 400 kWe power processor and a quasi-steady MPD arc jet thruster, with switching and logic required for operation at an exhaust velocity between 20 and 30 km/s, utilizing argon as a propellant. Specific mass of the thrust subsystem is presently estimated at less than 2 kg/kWe, designed for 30,000 hours of full power operation and a total lifetime of at least 90,000 hours.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Requirements for transport of a large number of different payloads from LEO to many different orbit locations with reusable upper stages are expected by the late 1980's. NEP will provide a low-cost, multi-payload, multi-mission reusable "Tug" capability. The MPD arc jet for this application is an exceptionally low-cost, versatile, lightweight device that will be able to operate at high thrust density with very little power processing.

b. Mission needs are particularly in the large payload transport from LEO to geosynchronous orbit or escape velocity.

c. NEP as a reusable trip for geosynchronous missions will provide approximately a factor of 4 larger payload to geosynchronous orbit than a chemical propulsion system. The round trip with NEP, however, takes slightly over 100 days. If payload delivery rate is compared over a large number of flights, the Shuttle with NEP tug will deliver payload at approximately 50% of the cost of using a chemical propulsion tug.

d. A ground prototype test is required, although it may also be desirable to have a short powered flight system test in space.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. II-A-(1)(c)

1. TECHNOLOGY REQUIREMENT(TITLE): MPD Thrust Subsystem Technology PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Because of the high energy mission capability of NEP, large orbit plane changes and orbit altitude changes may be carried out in preprogrammed sequences to deliver a variety of payloads to a variety of destinations within a single round trip, or to deliver a large payload to a single destination. Exhaust velocity is expected to be readily variable to provide any changes that may be required by the mission.

8. TECHNICAL PROBLEMS:

a. Subsystem definition
b. Efficiency optimization
c. Power processing for variable exhaust velocity
d. Thermal design of thruster anode

9. POTENTIAL ALTERNATIVES:

Ion engines may be used, at considerable increase of system mass, complexity, and cost.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Without special effort by NASA, this advancement would not occur.

EXPECTED UNPERTURBED LEVEL 2

11. RELATED TECHNOLOGY REQUIREMENTS:

This technology requires the availability of a nuclear power subsystem technology to accomplish the stated missions. It may also require further development of robotics and teleoperator technology for rendezvous and docking, payload servicing and/or deployment, etc.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. II-A-(1)(c)

1. TECHNOLOGY REQUIREMENT (TITLE): MPD Thrust Subsystem Technology PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design		—	—	—	—	—	—	—											
2. Fabrication							—	—	—	—									
3. Test											—	—							
4. Documentation													—						
5.																			
APPLICATION																			
1. Design (Ph. C)												—	—						
2. Devl/Fab (Ph. D)														—	—				
3. Operations																—			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE													X					
NUMBER OF LAUNCHES																	2	

14. REFERENCES:

15. **LEVEL OF STATE OF ART**

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. II-A-(2)(a)

1. TECHNOLOGY REQUIREMENT (TITLE): Solid Core Nuclear Rocket Technology PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: An assessment of applications to combined high-thrust/low-thrust missions is to be accomplished.

4. CURRENT STATE OF ART:

HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY

A direct heating, solid core, nuclear rocket technology would provide high thrust upper stage propulsion at a hydrogen exhaust velocity approaching 10 km/s. This should be assessed in combination with low-thrust propulsion, as a dual-mode system or a separate NEP system.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

This technology, because of its high thrust characteristic, perhaps ought to be re-evaluated in the light of other advanced technologies more recently being advocated. The advantage of relatively high exhaust velocity, however, appears to be partially offset by the large hydrogen tankage requirement. Possible combined high-thrust missions have not yet been explored within the context of planned STS capabilities.

TO BE CARRIED TO LEVEL N/A

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. II-A-(2)(b)

1. TECHNOLOGY REQUIREMENT (TITLE). Fluid Core Nuclear Propulsion Technolog, — PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: To complete the experimental characterization and the conceptual design of a high temperature plasma core nuclear rocket system.

4. CURRENT STATE OF ART: Basic and applied research is being conducted into the fluid flow and heat transfer of plasma core reactors.

HAS BEEN CARRIED TO LEVEL 1

5. DESCRIPTION OF TECHNOLOGY

Large, very high temperature, fissioning plasma cores in nuclear reactors have the potential capabilities of producing high thrust-to-mass propulsion at exhaust velocities up to 50 km/s. Such systems require the storage and/or recirculation of fissionable materials outside the reactor, and a fairly complete separation of fluid flow between the hydrogen propellant and the fissioning plasma within the reactor core. Both the "open cycle" and "light bulb" concepts of the plasma core nuclear rocket require evaluation Hot nuclear fuel is confined in the reactor cavity and separated from walls and structure by the flow of a buffer gas. There are two basic schemes: In the coaxial flow or "open cycle" device, the buffer gas is to intercept the optical radiation from the fissioning plasma. It is thus heated and by expansion through a nozzle, it produces thrust. In the nuclear "light bulb" engine, the plasma fuel and buffer gas are contained in a transparent cylinder. Radiation from the plasma heats up a propellant flowing about the nuclear "light bulb".

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

V large, high energy manned missions, such as manned planetary expeditions may be expected sometime beyond the year 2000. Such missions will require some combination of high thrust and high specific impulse propulsion. It is therefore important to carry the plasma core nuclear propulsion to the point of validated conceptual design in order to allow a fairly comprehensive comparison with other systems which have been carried to a higher level of the state of the art. Further need for technolog advancement can then be assessed.

TO BE CARRIED TO LEVEL 3

DEFINITION OF TECHNOLOGY REQUIREMENT NO. II-B

1. TECHNOLOGY REQUIREMENT (TITLE): Nuclear Fusion Propulsion PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: A continuing assessment is needed of high-energy fusion research as the phenomena move toward experimental demonstration.

4. CURRENT STATE OF ART:

HAS BEEN CARRIED TO LEVEL 0

5. DESCRIPTION OF TECHNOLOGY

A number of concepts have been proposed for the use of nuclear fusion to generate thurst. They presently include microexplosion concepts (laser generated) and controlled thermonuclear reactors (CTR). These concepts represent a future opportunity to obtain much higher energy densities than by nuclear fission, and thereby represent a follow-on technology of potential importance.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Fusion energy systems represent the first possibility for space exploration well beyond our Solar System. Such missions are beyond the year 2000, but represent, to some extent, an important aspect of future planning. At this time NASA represents a technology observer and planner rather than an active participant.

TO BE CARRIED TO LEVEL N/A

DEFINITION OF TECHNOLOGY REQUIREMENT NO. II-C

1. TECHNOLOGY REQUIREMENT (TITLE): Combined Radioisotope Thermoelectric/Propulsion Module PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: To utilize the direct heating capability of a radioisotope thermoelectric generator for propulsion performance enhancement.

4. CURRENT STATE OF ART: Isotopic thermoelectric generators have been built for flight. Radioisotope heating of propellant has been done on a laboratory scale. They have not been combined. HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

At present thermoelectric generators and propulsion systems are designed as separate systems for a particular mission. Some types of auxiliary propulsion are significantly enhanced by additional heat input. The required advancement is to produce an integrated system. The technology needed is basically existent but a great deal of effort is required in the design stage to marry the two technologies.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. An increase in propulsion system efficiency by utilizing "waste" heat from an RTG would reduce total spacecraft weight, a factor of particular importance on deep space missions where RTG units are typically applied.

b. The technology would be applied to earth orbit and interplanetary missions for which RTG units are required.

c. The radioisotope thermoelectric generator is typically applied to deep space missions where any extention of mission life time is of great value. Increased performance of the auxiliary propulsion system extends useful mission life-time and/or capability by conserving propellant.

Some types of sensors are incompatible with high energy propellant exhaust products and force the use of cold gases. Auxiliary heating can more than double the specific impulse in these cases.

d. Breadboard system level testing in vacuum.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO. II-C

1. TECHNOLOGY REQUIREMENT(TITLE): Combined Radioisotope Thermoelectric/Propulsion Module PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

8. TECHNICAL PROBLEMS:

Thermal transients may produce structural problems. Reducing thrust chamber size for efficient attitude control pulses is of concern. Transient depression of electrical output may be a problem.

9. POTENTIAL ALTERNATIVES:

Use the less efficient electrical output for ohmic heating of the propellant.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 3

11. RELATED TECHNOLOGY REQUIREMENTS:

None

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. II-C

1. TECHNOLOGY REQUIREMENT (TITLE): Combined Radioisotope Thermoelectric/Propulsion Module PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/design																			
2. Fabrication																			
3. Test																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. III-A-(1)

1. TECHNOLOGY REQUIREMENT (TITLE): Direct Heated Laser and Microwave Propulsion PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Evaluate concepts and establish potential of propulsion by heating of propellants by a laser beam transmitted from an external source.

4. CURRENT STATE OF ART: Possible gas phase absorbtion mechanisms analyzed.

HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

The major technology areas include appropriate laser systems, beam transmission phenomena, laser-beam receiver systems, conversion of laser beam energy to sensible propellant enthalpy, and viable thruster designs. Preliminary analysis of energy absorbtion mechanisms and propellant stability in the thruster is complete. Preliminary absorbtion/flow visualization tests near completion. Complementary analytical and experimental evaluation of high power laser systems is in progress.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a) The exact specifications on the technology performance parameters will be determined by the analytical and experimental studies of the various elements of this technology area.

b) A broad class of missions would benefit from the promise of greater than 1000 sec. impulse propulsion without a requirement of on-board propulsive power.

c) This is an opportunity driven technology.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT

NO.III-A-(1)

1. TECHNOLOGY REQUIREMENT(TITLE): Direct Heated Laser and Microwave Propulsion

7. TECHNOLOGY OPTIONS:

The system trades and sensitivities will await definition of basic technology performance parameters and feasibility analysis. Trades will exist for the source of the energy (eg.: space, aircraft, and earth); propellant type; laser beam generator (efficiency, lifetime) and beam characteristics; and on-board thrust subsystem characteristics (such as thruster temperature limits).

8. TECHNICAL PROBLEMS:

1. Propellant absorbtion, propogation, generation, and steering of the laser beam.

2. High temperature thrusters.

3. Laser optics systems.

9. POTENTIAL ALTERNATIVES:

In the area of beamed energy a potential alternative is to utilize on-board devices to connect the beams to electrical power for subsequent use in an electric propulsion system.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP 506-21-40 "Laser Propulsion Technology"

EXPECTED UNPERTURBED LEVEL 4

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. III-A-(1)

1. TECHNOLOGY REQUIREMENT (TITLE): Direct Heated Laser and Microwave Propulsion PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Element Analysis																			
2. Systems Analysis																			
3. Preliminary Tests																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE																		TOTAL
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. III-A-(2)

1. TECHNOLOGY REQUIREMENT (TITLE): Laser and Microwave Electric Propulsion Technology PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: To complete the experimental characterization and the conceptual design of a laser and microwave power transmission and conversion in space for primary electric propulsion.

4. CURRENT STATE OF ART: Basic and applied research is being conducted in visible laser and microwave power transmission and conversion to electricity.

HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

Visible wavelength laser energy and/or microwave beamed energy from an orbiting spacecraft or other remote site is transmitted to other vehicles (orbiting satellites or surface rovers) and is then converted to electrical energy and utilized for propulsion. Conceptual definition is required for proper evaluation of the technology.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

The proposed technology represents an opportunity among other applications, to utilize mother-daughter vehicle operations at the outer planets, where solar power is not available. In order to adequately compare this technology to other systems which have been carried to a higher level of the state of the art, advancement of the technology is required. If the resultant concepts are promising, further technology advancement can then be recommended.

TO BE CARRIED TO LEVEL 3

DEFINITION OF TECHNOLOGY REQUIREMENT NO. III-B-1-(a)

1. TECHNOLOGY REQUIREMENT (TITLE): Auxiliary Electric Propulsion System Technology with Mercury Bombardment Thrusters PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: To bring to a state of technology readiness attitude control and stationkeeping systems for geosyncronous spacecraft using mercury bombardment thrusters.

4. CURRENT STATE OF ART: Engineering model level hardware based on extensive precurser development and demonstration, is in the fabrication phase.

HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY

An auxiliary propulsion system consists of a thruster, thrust vectoring subsystem, propellant supply and distribution subsystem, power processor and associated structural and thermal control elements. The system reliability must be sufficient to provide efficient, light-weight geosynchronous satellite control over time periods up to about ten years at a specific impulse of about 3000 seconds. The required system technology is nearly all available and successful thruster and ongoing critical element life tests of over 13,000 and 20,000 hours, respectively are in progress. An engineering model level auxiliary propulsion system is in the fabrication phase with full system qualification and complete lifetime demonstration of the baseline system scheduled for completion by the middle of fiscal years 76 and 79, respectively. Minor redesigns to provide for optimal system performance for a variety of spacecraft concepts are under development.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a) The baseline auxiliary propulsion system values of specific impulse ($\sim$ 3000 seconds) thrust ($\sim$1 mlb.), propellant loading, and thrust vectoring capability were selected as optimal for north-south stationkeeping of a large class of geosynchronous satellites less than about 3000 kg in mass which utilize solar power for thruster operation.

b) In general, long life advanced geosynchronous satellites will benefit from this technology. The majority of the applications are for on-orbit stationkeeping operations in the disciplines of Earth Observation, Communication and Navigation, and Non-NASA/Non DoD Payloads.

c) As an example of mass savings, the use of ion thrusters reduces the satellite control propulsion system from 21 to 10 percent of total spacecraft seven year mission with larger proportional saving arising for longer missions. In addition, the low levels of finely controlled thrust allow for more control precision.

d) This technology should be carried to an experimental demonstration on an automated spacecraft or on an early shuttle flight.

TO BE CARRIED TO LEVEL

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. III-B-1-(a)

1. TECHNOLOGY REQUIREMENT(TITLE): Auxiliary Electric Propulsion System Technology with Mercury Bombardment Thrusters

7. TECHNOLOGY OPTIONS:

Design at approximately twice the baseline thrust level ot optimize system performance with a battery power source is possible.

Redesign of power processor to take advantage of high voltage solar arrays is possible as the operating concept has been demonstrated.

8. TECHNICAL PROBLEMS:

1) Potential ion beam/spacecraft interactions for body mounted thrusters.

2) Possible structural/dynamic problems for end of the array mounted thrusters.

9. POTENTIAL ALTERNATIVES:

In the range of specific impulse greater than about 800 seconds, no alternate technology options to some form of electric propulsion presently exist or are proposed for auxiliary propulsion (Reference 1). Two other electric propulsion systems--electron bombardment thrusters using cesium propellant and colloid thrusters--are presently under development. The former is generically quite similar to the mercury bombardment systems while the latter (colloid) operates at a specific impulse of about half that of the mercury systems.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP 502-22-11 "Auxiliary Propulsion Ion Thruster Technology"

NASA Resources are required for advancement of technology beyond present STATE of ART.

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

Guidance, Navigation and Control for low thrust propulsion systems.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. III-B-1-(a)

1. TECHNOLOGY REQUIREMENT (TITLE): Auxiliary Electric Propulsion System Technology with Mercury Bombardment Thrusters PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design																			
2. Fabrication																			
3. Test																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	TOTAL
TECHNOLOGY NEED DATE		∇															
NUMBER OF LAUNCHES						1											

14. REFERENCES:

1) Outlook for Space. A Forecast of Space Technology --- Final Draft, July 15, 1975

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. III-B-(1)

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Electric Primary Propulsion Thrust Subsystem Technology PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: To bring to a state of technology readiness a primary solar electric propulsion thrust subsystem utilizing mercury bombardment thrusters.

4. CURRENT STATE OF ART: Thruster and power processor developed to engineering model and thermal vacuum breadboard levels, respectively. Other system elements developed to at least functional status.

HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY

The major elements of a SEP system are the mercury bombardment thrusters, power processors, propellant feed and distribution system, thrust vectoring system, thrust subsystem controller, and associated solar array power system. The required system characteristics include specific impulse of about 3000 seconds, overall efficiency of about 65%, reliability commensurate with thrusting times of 15,000 hours or more, and operational capability over the spectrum of environments from 0.7 to 4 A.U. The thruster has been developed to Engineering Model level with thermal and structural qualification and a 10,000 hour life test completed. The power processor has been developed to the thermal vacuum breadboard level with a program to provide packaged functional models in progress. A lightweight solar array concept has been developed to a demonstration level. Other elements require minor or no extension of existenc technology.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a) The required baseline SEP parameters and characteristics of 3000 seconds specific impulse, lifetime of 15,000 hours or greater, input power and thrust capability, and efficiency and mass goals of 65% and 12 kg/kw respectively, are selected as optimal for satisfaction of the requirements of a broad set of planetary and near earth missions.

b) In general, planetary and near earth missions characterized by high energy and/or high performance requirements are strongly benefited by the use of a high specific impulse propulsion system. Examples of such missions are: interplanetary transport such as comet rendezvous and out-of-the-ecliptic missions; and transportation and on orbit operations missions which utilize shuttle capability.

c) Significant payload and performance benefits accrue with the use of this technology for high energy performance sensitive missions.

d) This technology should be carried to an experimental demonstration on an automated spacecraft or on an early shuttle flight.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. III-B-(1)b

1. TECHNOLOGY REQUIREMENT(TITLE): Solar Electric Primary Propulsion Thrust Subsystem Technology PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

In the advent of substantial reductions in power source specific mass the optimal specific impulse would increase with subsequent propellant savings. Increases of up to about a factor of 2-3 could be achieved without major technology effort except in the power conditioning interface between power source and load.

Significant (15%) reductions in thrust subsystem mass could be expected if the thruster high voltage requirements were provided directly without power conditioning via a high voltage solar array system. In addition, use of an alternate power source, such as nuclear, would greatly expand the thrust subsystem a very attractive transportation stage for very large space systems such as SPS (REF. 2).

8. TECHNICAL PROBLEMS:

1) Spacecraft integration.

2) The target of 12 kg/kwe.

9. POTENTIAL ALTERNATIVES:

1) Use of light fuels instead of mercury.

2) Use of magnetoplasmadynamic (MPD) thrusters with reduced efficiency.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP 506-22-30 "Prime Propulsion Ion Thruster Technology"

The technology would not be expected to advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

Guidance, navigation, and control for low thrust systems.
Structural dynamics of large flexible spacecraft.
Thermal control of large power systems.

CV

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. III-B-(1)b

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Electric Primary Propulsion Thrust Subsystem Technology

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design																			
2. Fabrication																			
3. Test																			
4. Documentation																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE					X													
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. III-B-(1)-(c)

1. TECHNOLOGY REQUIREMENT (TITLE): Primary Electric Propulsion (SEP) with Low-Melecular Weight Propellant Bombardment Thrusters — PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide the technology for an efficient high specific impulse electric propulsion system for very large space systems in near earth environment using low cost, plentiful, inert fuels

4. CURRENT STATE OF ART: Thruster operation has been demonstrated with a variety of low-molecular weight propellants (LMWP) with several sizes and types of thrusters. HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

The major elements of a primary electric propulsion system with L.M.W.P. bombardment thrusters are the bombardment thrusters, power processing, thrust vectoring equipment, propellant supply and distribution system, thrust subsystem controller, attitude control system, and power source. The major technology requirements beyond those for a mercury bombardment thrust subsystem (reference 1) are the development of an optimally sized efficient long-life light fuel thruster; suitable scaled or modified power processing; propellant supply and distribution system; and, for some applications, development of new power source. Lifetime requirements are likely to range up to 5 years or more dependent upon the particular application (reference 2).

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a) The selection of plentiful, low cost, and inert propellant is based on the requirements for an orbit oerations and transportation of proposed very large near-earth missions using shuttle capability. In these applications, large amounts of power are available for propulsion system and overall system performance is strongly optimized by operation at specific impulses well in excess of that available from chemical propulsion systems.

b) This technology would benefit the low earth to geosynchronous orbit and on-orbit operations propulsion systems for very large near earth space systems which result from full application of shuttle capability.

c) Operation at high specific impulse would be expected to significantly decrease propellant requirements for both transportation and on-orbit operations. An increase of the geosynchronous orbit payload capability of a shuttle based system is estimated in one application to be a factor of 9 (reference 2), at some expense in flight time.

d) This technology should be carried to an experimental demonstration on an early shuttle flight.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. III-B-1-(c)

1. TECHNOLOGY REQUIREMENT(TITLE): Primary Electric Propulsion(SEP)with Low-Molecular Weight Propellant Bombardment Thrusters PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

A wide range of specific impulses are available from a developed system without significant impact on the technology baseline. A baseline system could therefore provide optimal specific impulse for low earth orbit to geosynchronous transportation and on-orbit operations of very large space systems. Operation on new improved power sources would not change the required thruster, propellant supply and distribution system, thrust vectoring or thrust system control system technology.

8. TECHNICAL PROBLEMS:

1. Achievement of a high efficiency, long life, low-molecular-weight propellant require some redesign of the baseline mercury bombardment systems.
2. Thermal control of the thrust subsystem would be difficult and probably require the use of heat pipe and other emergent technology.
3. Propellant supply and distribution sys·em.

9. POTENTIAL ALTERNATIVES:

1. Use of a magnetoplasmadynamic thruster.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP 506-22-40 "Ion Thruster Research"
The technology would not be expected to advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 4

11. RELATED TECHNOLOGY REQUIREMENTS:

Guidance, Navigation and Control of large/flexible spacecraft using low thrust.

Structural dynamics of large/flexible spacecraft.
Advance thermal control and power distribution technology.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. III-B-(1)-c

1. TECHNOLOGY REQUIREMENT (TITLE): Primary Solar Electric Propulsion(SEP) with Low-Molecular Weight Propellent Bombardment Thrusters PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design																			
2. Fabrication																			
3. Test																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE						(*)											
NUMBER OF LAUNCHES																	

14. REFERENCES:

1. Definition of Technology Requirements for Primary Solar Electric Propulsion (SEP) with Mercury Bombardment Thrusters.

2. Satellite Solar Power Station Study
Arthur D. Little, Inc., Gruman, Spectrolab, and Raytheon. Feb. 14, 1973
NAS 3-16804

3. Outlook for Space. A Forecast of Space Technology, Final Draft July 15, 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. III-B-(2)

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Heated H_2 Propulsion PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: High Performance, low cost chemical system for transporting payloads from low earth orbit to geosynchronous orbit and beyond.

4. CURRENT STATE OF ART: Feasibility study has been performed by TRW that shows system to be promising as competitor to SEP for the types of missions mentioned above. HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

A propulsion system has been postulated by TRW that utilizes a solar collector to concentrate thermal energy for direct heating of stored LH_2 for propulsion. Further studies are needed to evaluate the concept, perform trade studies, and provide preliminary design of the optimum system. If the approach looks promising, component development activities would be undertaken on the solar collector and receiver, fluid storage and transfer systems, and the main propulsion engine, followed by systems tests.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

(a) Critical parameters are dependent upon the system design selected, but would generally include system operating pressures, thrust level, and total delivered impulse.

(b) Application is for transport of payloads from low earth orbit to geosynchronous orbit or to escape velocity.

(c) The advantages of this approach are simplicity and low development cost compared to an SEP or a high thrust chemical propulsion system.

(d) Technology should be carried through systems level testing in a thermal/vacuum chamber to fully demonstrate maturity and readiness for use.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO. III-B-(2)

1. TECHNOLOGY REQUIREMENT(TITLE): Solar Heated H_2 Propulsion PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

8. TECHNICAL PROBLEMS:

The principal technical problems are related to structural design of the lightweight solar collector, design of the solar energy receiver, routing of heated gaseous hydrogen to attitude control thrusters, the main thruster design, and long life hot gas control valves.

9. POTENTIAL ALTERNATIVES:

Alternative methods of performing the missions are solar electric propulsion (SEP) systems and high thrust chemical stages like space tug.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Unperturbed Program - Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 2

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. III-B-(2)

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Heated H_2 Propulsion — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. System Studies		—	—																
2. Preliminary Design				—															
3. Detailed Design/ Fabrication					—	—													
4. Component Tests						—	—	—	—										
5. System Tests									—	—	—								
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	TOTAL
TECHNOLOGY NEED DATE										Δ							
NUMBER OF LAUNCHES																	

14. REFERENCES:

(1) Burge, H.: "Solar Heated Hydrogen Propulsion System for Space Tug", TRW Company Report, 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

REFERENCES:

(1) "Outlook for Space Reference Volume: A Forecast of Space Technology 1980-2000," NASA Special Publication January, 1976.

(2) Tischler, A.O. Astronautics and Aeronautics, p. 26, July/Aug. 1975

NASA

Office of Aeronautics and Space Technology

Summer Workshop

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Final Report

PROPULSION TECHNOLOGY PANEL

(part II)

Volume V of XI

Part II
CANDIDATE SPACE EXPERIMENT PAYLOADS

TABLE OF CONTENTS

PART II CANDIDATE SPACE EXPERIMENTAL PAYLOADS

1. INTRODUCTION

The Part I Report (Technology Requirements) treats the justification for several classes of propulsion systems technologies to be pursued through the year 2000. The objective of the Part II Report is to introduce and discuss the experimental aspects of these technologies that might be advantageously carried out in near-earth space using the Shuttle Orbiter, its payload bay, the Spacelab, and/or some free-flying device that might be used for long-duration testing.

The entries discussed by the Propulsion Technology Group are shown in the Table of Sections which serves also as a supplementary Table of Contents. The entries are grouped in the following three categories according to the principal rationale for carrying out the experiments in space:

1) The special characteristics of the space environment makes testing from the Shuttle Orbiter and its related equipment the only, or the most reasonable approach to obtaining data.

2) Testing in space is expected to be more cost-effective than carrying out similar tests on earth.

3) Tests in near-earth space provide a very close approximation to the conditions to be encountered by operating systems and as such may reveal unforeseen problems of operations in space or may otherwise provide risk reduction for the hardware design. In this way, space testing will aid in gaining user acceptance of a new technology.

The objective, description, and justification for each entry are provided on the Definition of Technology Requirement form and on the second page of the Future Payload Technology form. These forms are presented in Section 5 of this report on the pages shown in the following Table. The forms were completed only as time permitted and as information was readily available. This same information is summarized in Section 4.

In the case of several entries shown in the Table, propulsion-related technology was discussed by another Group and is presented in their final report. In these instances, only a summary is included in this report, and the Technology Group to which the item was referred is identified.

2. TABLE OF CANDIDATE SPACE EXPERIMENTAL PAYLOADS

Space Payload Justification Categories

I. Space Environment <u>Essential</u>

II. Space Experiment <u>Most Cost Effective</u>

III. Space Demonstration to <u>Reduce Risk</u>

No.	Title	Justification Category
E1	Spacecraft Charging and High Voltage Interactions with Plasma (submitted to Power Technology Group)	I
E2	Flight Test of 8-cm Bombardment Thruster	I
E3	High Temperature Plasma Core Reactor Fluid Mechanics (low-g) (submitted to Basic Research Technology Group)	I
E4	Vibration Test of Solid Rocket Motors	I
E5	The Storage Supply and Transfer of Cryogenic Fluids in Space(submitted to Thermal Control Group)	I
E6	Propellant Management Device Design Parameters at zero-g	I
E7	Thruster Induced Back Contamination	I
E8	Supercritical Combustion Measurements in zero-g	I
E9	Pulse Characteristics of Small Thrusters	I
E10	Flight Test of Composite Engine	I
E11	Deployment/Assembly and Control of Large Space Propulsion Energy Sources (Solar Sails, Solar Energy Concentrators, Solar Photovoltaic Panels)	I
E12	Sublimation Properties of Solidified Propellants	I

No.	Title	Justification Category
E13	Flight Test of SEP Thrust SubSystem	II, I
E14	Flight Test of Low Molecular Weight Propellant Bombardment Thruster	II
E15	Space Storability of Solid Rocket Motors	II, III
E16	Measurement of Solid Rocket Motor Thrust Alignment	III
E17	Final Qualification Test of N_2H_4Resistojet	III
E18	Final Qualification of F_2/N_2H_4 Propulsion System	III
E19	Final Qualification Test of Cesium Ion Engine	III

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3. SUMMARIES OF CANDIDATE EXPERIMENTAL PAYLOADS

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I. Title:

Spacecraft Charging and High Voltage Interactions with Plasma

II. Objective:

Determine theory and verify by space obtained engineering data the interactions of charged surfaces with plasma.

III. Description:

The experiment would be a satellite launched from the Shuttle or a Delta with a geosynchronous to low earth orbit. The interactions of spacecraft surfaces in a variety of configurations and charge state are to be investigated.

IV. Justification:

A number of spacecraft have experienced interactions with ambient plasmas which have in some cases endangered the spacecraft. Tests in the actual space environment are required to accurately determine spacecraft design criteria.

I. Title:

Flight Test of 8-cm Bombardment Thruster

II. Objective:

Demonstrate the technology readiness of the 8-cm electron bombardment ion thruster. Demonstrate the compatibility of electric propulsion systems with science oriented missions. Evaluate plasma interactions and environmental measurements.

III. Description:

The experiment would consist of two 8-cm ion thrusters systems with sufficient solar array power to operate a thruster even after array degradation. The thrust subsystems would be run to demonstrate cycle life performance equivalent to 10 years of stationkeeping. Other diagnostic data such as the evaluation of the impact of thruster operation on S-bank communications, measurement of any thruster back contamination, and the influence of thruster operation on particle and field measurements would be made. A test of solar array operation at up to one kilovolt would be made to evaluate high voltage array interactions and possibly to test thruster operation off unconditioned solar array power.

IV. Justification:

The demonstration of technology readiness of auxiliary electric propulsion and compatibility with communication, scientific, and other spacecraft systems would allow confident application of this technology to a large class of geosynchronous satellites and provide large mass (or cost) savings and improved precision of control.

I. Title:

High Temperature Plasma Core Reactor Fluid Mechanic (Low-g)

II. Objective:

To study the fluid mechanics of high density and low density flow separation in a low-g environment.

III. Description:

The open cycle plasma core nuclear rocket requires nearly complete separation of the flow of the propellant from the fissioning plasma. Low density propellant is expended, while the high density nuclear fuel is to be retained in the core.

IV. Justification:

Laboratory experiments are currently significantly influenced by gravity. A need, therefore, exists to conduct this experimental research in a low-g environment.

I. Title:

Vibration Test of Solid Rocket Motor

II. Objective:

To determine the effect of the Shuttle acoustic and vibrational environment on solid rocket motor integrity and the response of the propellant to the Shuttle vibration environment.

III. Description:

The early Shuttle flights could carry a small test model or motor with instrumentation which would provide data on the response of the propellant and insulation system to this environment. These data would then be used in future design of solid rocket kick motors.

IV. Justification:

It is very difficult to analyze or determine design parameters and the values which describe the requirements for the vibration environment for a viscoelastic material such as a solid propellant. The early Shuttle flights appear to offer a mechanism for obtaining the data in a cost-effective manner.

I. Title:

The Storage, Supply, and Transfer of Cryogenic Fluids in Space (Submitted to the Thermal Control Technology Group)

II. Objective:

Perform flight experiments in space to obtain technology on the storage, handling, supply, and transfer of cryogenic fluids.

III. Description:

"In space" experiments will be performed to obtain data with cryogenic fluids such as LH_2, LO_2, LF_2, LHe, and LAr. Technology related to propellant long term storage (tests of several days duration), receiver tank childown, propellant or fluid acquisition for pumping, propellant transfer including inflow/outflow problems, pressurization gas requirements, pressurization system design, and vehicle reaction to propellant momentum change.

IV. Justification:

Technology in this area has been obtained on the ground in two ways: (i) long term thermal/vacuum tests of moderate sized hardware in one-g; and (2) short term test (5 seconds) of small hardware in zero-g in drop towers and aircraft. Inspace experiments will allow data to be obtained under actual rather than simulated conditions of vacuum and zero-g using large sized hardware (e.g., 8-10 ft. diameter) for long periods of time. Tests will provide design data needed for a number of cryogenic systems for future space application.

I. Title:

Propellant Management Device Design Parameters at zero-g

II. Objective:

Improve the analytical tools required to design surface tension type propellant management, pressurant, and outflow devices.

III. Description:

A self-contained package (including instrumentation) would be carried by Shuttle into zero-g environment. While in orbit, experiments would be conducted to obtaining design information on the interaction between propellant and injected pressurant, effects of contamination on the surface tension properties of liquid propellants, wicking properties of materials used for surface tension devices, and propellant outlet design for tanks in the size range of the order 1m in diameter containing surface tension propellant management device.

IV. Justification:

Parameters required for the design of surface tension type propellant management devices have been based on either ground tests or results from drop tower tests. Neither are satisfactory in that gravitational effects or short time durations have clouded results. Inspace testing allows several types of systems to be considered whose use cannot be accepted because of limitations in the ability to confirm functionality in ground tests.

I. Title:

Thruster Induced Back Contamination

II. Objective:

Determine far-field plume map and back contamination (including solid particles) from chemical and electrostatic thrusters.

III. Description:

A modular propulsion system with contamination sensors (Quartz and crystal microbalances) would be carried up by the Shuttle, deployed, fired, and measurements taken. Chemical thrusters, both solid and liquid (bipropellants and monopropellants), as well as electric thrusters would be tested in order to ascertain the degree of surface contamination and degradation.

IV. Justification:

Existing ground facilities do not have the pumping capacity to test large engines (up to 500 lbf). Space provides the only adequate test conditions.

I. Title:

Supercritical Combustion Measurements in zero-g

II. Objective:

Establish supercritical droplet evaporation/combustion rates and flammability limits in zero-g.

III. Description:

A self-contained module would be fabricated after the individual measuring devices are developed, checked out, and qualified. This module would then be mounted in the Spacelab in order to make the measurements described in the objective.

IV. Justification:

Design and development of advanced combustion systems for rocket and jet propulsion can be significantly aided by using computerized combustion models for performance prediction. However, current prediction accuracy is limited because required input data is obtained in the one-g environment which precludes the separation of gravity effects from other convection effects and thus limits the generalization of the models. Experiments conducted at zero-g would eliminate this problem.

I. Title:

Pulse Characteristics of Small Thrusters

II. Objective:

To refine the measurement of impulse bits from small thrusters and thus to allow design of more efficient spacecraft attitude control systems.

III. Description:

Use an inertial reference to measure impulse bits produced by a thruster mounted on a free-flying platform in space.

IV. Justification:

All spacecraft utilizing attitude control thrusters in the low to high millipound thrust range and below would benefit from a more accurate knowledge of impulsa bit characteristics from the standpoint of precise matching of force to control requirement and the related fuel savings. Resolution of impulse bit profile in ground test is limited by environmental noise and ground related design waeknesses of the thrust balance itself.

I. Title:

Flight Test of Composite Engine

II. Objective:

Use Shuttle Orbiter vehicle as a flying test bed for cruise mode tests of full scale composite engine.

III. Description:

Flight tests of composite engine in the atmosphere will be conducted to verify performance, controllability, and structural integrity of the full scale engine. Shuttle would be either launched vertically using smaller SRB's or carried aloft by 747 aircraft. Composite engine will then be started and cruise mode tests conducted at high altitude and Mach number. Orbiter will then land without propulsion in its normal fashion.

IV. Justification:

Flight test of composite engine would cost less than construction and operation of a ground test facility having the required capabilities of heated air flow and altitude simulation. Also, flight testing will allow greater testing flexibility and provide a more convincing demonstration of technology readiness than ground testing.

I. Title:

Deployment/Assembly and Control of Large Space Propulsion Energy Sources

II. Objective:

To verify and/or define by a sequence of flight experiments the multi-discipline element and system technology, including propulsion system performance parameters, required for the deployment/assembly and control of large space propulsion energy sources.

III. Description:

A sequence of space experiments which would provide timely and orderly space verification of the system and discipline technologies required for large space systems. Initial experiments would be operated from the Shuttle based test bed and would include: testing of deployment/assembly/fabrication concepts for large space systems; evaluation of potential materials and structures concepts to characterize such properties as solar flux reflection and absorption, structural static and dynamic properties as a function of design approach, environmental radiation compatibility; and verification of attitude control and propulsion subsystem designs. Subsequent tests would utilize a low cost free-flying test bed to provide a more realistic simulation of large space system on-orbit and/or transportation configurations and system characteristics. Multidiscipline technology would be verified and defined on an on-going basis with the investigation of the additional concepts of the refurbishment and resupply, assembly, and control of a free-flying large space system.

IV. Justification:

The technology for the successful exploitation of large space systems remains largely undefined and/or undemonstrated. An on-going space experimental program to define and/or verify systems designs including that of the propulsion subsystem would be required to provide timely, optimal, and highest reliability use of large space systems.

I. Title:

Sublim tion Properties of Solidified Propellants

II. Objective:

To evaluate the effects of zero-g on sublimation rates and hear transfer of selected solidified propellants to allow better prediction of the performance of sublimation sensor coolers/propellant supply systems in space.

III. Description:

Appropriate tanks containing candidate propellants cooled to the solid state are tested in the laboratory to establish baseline performance for comparison with subsequent similar tests carried out in the zero-g space environment. Typical propellants to be considered are methane an ammonia.

IV. Justification:

Gravitational effects of convection and forced contact of the solid with the container are not succeptable to reasonable calculation when attempting to extropolate the calculation of heat transfer/sublimation rates in zero-g space. Sensor cooling by a sublimating frozen substance is one of the simplest methods being proposed. The sublimated gas could be used to fuel the attitude control system thus permitting a combined function system with the attendant simplification and probable cost savings.

I. Title:

Flight Test of Solar Electric Propulsion Thrust Subsystem

II. Objective:

To verify and characterize by flight test the performance parameters, interfaces, lifetime, and reliability of a solar electric prime propulsion thrust subsystem. To provide baseline electric propulsion parametric data to allow extension of this technology to use with large space systems for transportation and on-orbit operations. To utilize the unique electric propulsion mission characteristics to provide new or extended scientific and engineering information concerning near-earth and other solar system phenomena.

III. Description:

The experiment would contain an array of 30cm bombardment thrusters, power processing units, thrust vectoring mechanisms, electrically isolated propellant supply and distribution system, thrust subsystem controller, appropriately scaled solar array, attitude control system, and scientific and diagnostic engineering data systems. Dependent upon NASA and other priorities, a potential first mission could be carried out on a low cost test bed launched from the Shuttle or a free-flying out-of-the ecliptic probe launched from the Shuttle to provide both new scientific and the required subsystem engineering data.

IV. Justification:

The benefits of a high impulse, high performance propulsion system for a broad set of high energy missions has been well documented in many studies. A flight test of the thrust subsystem would: (1) verify and extend the ground-based technology readiness status of electric propulsion, (2) provide sufficient parametric data for the low risk extension of the baseline technology to proposed future missions, and (3) return new scientific data which can be obtained only by a high performance propulsion system.

I. Title:

Flight Test of a Low Molecular Weight Propellant Bombardment Thruster

II. Objective:

Verify and characterize the performance parameters, lifetime, reliability, and interfaces of an electron-bombardment thruster operated on a low molecular weight propellant by a flight test on the Shuttle and a subsequent free-flying test bed.

III. Description:

The test would consist of operation of a single bombardment thruster on the Spacelab pallet with brassboard power processing compatible with the Spacelab power source. A prototype thruster, thruster controller, propellant supply and distribution system, and thrust vectoring mechanism would be tested. The initial test would be aimed at characterizing thruster interfaces and verifying performance parameters obtained from ground-based testing. Later, a free-flying test bed launched from the Shuttle would be utilized to life test the thruster and other system elements in such fashion as to insure lower risk use of the light fuel technology for MPD thruster application.

IV. Justification:

The use of electron-bombardment thrusters using low molecular weight propellants would provide performance increases, reduce costs, and minimize environmental impact of the STS system and the propulsive on-orbit operations of large space systems in near-earth environment. In addition, this technology would provide a baseline for high specific impulse propulsion systems using MPD thrusters. Due to the difficulty and expense of ground simulation of the space environment with large propulsion systems, a space test is required to fully verify system performance parameters, interfaces, and lifetime.

I. Title:

Space Storability of Solid Rocket Motors

II. Objective:

To demonstrate the space storability of a solid rocket motor.

III. Description:

It has been very difficult and expensive to provide long term tests which simulate the space environment to confirm the potential reliability of solid rocket motors, and thus it has not been accomplished. The Space Shuttle appears to be able to provide ready access to the actual environment with return of the exposed test items to earth for inspection and tests. Test exposures need to be 1 to 5 years with samples returned to earth for propellant mechanical properties, bond strength, and ignition measurements.

The tests should be of the margin type in which test articles are fabricated such that a failure probability of 50% could be expected. This provides the limiting data with which to design future motors. Also, the data would indicate the effect of combined parameters. LDEF appears to be suitable for this experiment.

IV. Justification:

The space environment has been too expensive to simulate on earth for long durations, and yet solid rocket motors are being proposed for use on planetary missions with space exposure. Long duration space exposure can provide valuable criteria for the design of future improved solid rocket motors, and reduce the risk of the first use of solid rocket motors for long term space missions.

I. Title:

Measurement of Solid Rocket Motor Thrust Alignment

II. Objective:

To use zero-g and space vacuum to determine thrust alignment parameters and values.

III. Description:

Currently, solid rocket motors can be fabricated with thrust alignment errors which are less than our ability to measure them on the ground due to the one-g field and interactions of the thrust stand. By using an expanding cold gas as an experimental simulation of a solid rocket motor nozzle under zero-g space vacuum, the small motions can be measured and resolved without thrust stand or gravitational interference.

IV. Justification:

Filling of a nozzle during ignition and thrust build-up, and the contributors to thrust alignment are not well understood, and because of the dynamic nature more are difficult to measure. Several vehicles have experienced large side loads during the staging or ignition phase. By using the Shuttle and the space environment, the increase in knowledge of the contributors to thrust misalignment should be greatly improved. This understanding will provide greater reliability and decrease the weight and cost of future TVC systems.

I. Title:

Final Qualification Test of Hydrazine Resistojet

II. Objective:

To qualify a new type of thruster (hydrazine resistojet) as space proven hardware to make it available as a prime system component for spacecraft.

III. Description:

Hydrazine is thermally decomposed in the chamber of an attitude control size thruster. Operation is varied by changes in heater power and pulse width.

IV. Justification:

Attitude control systems are required increasingly to perform reliably and repeatedly for longer periods of time with more operating cycles. The hydrazine resistojet has no catalyst bed and so has the potential for very high operating cycle life with highly repeatable pulses. The specific impulse is slightly higher than the equivalent catalyst bed thruster. The minimum impulse bit achievable approaches the size obtainable with cold gas which tends to save fuel and/or give finer attitude control.
The flight demonstration will fully qualify the hydrazine resistojet concept for application to earth orbit spacecraft.

I. Title:

Final Qualifications of an F_2/N_2H_4 Propulsion Subsystem

II. Objective:

Provide final verification of design adequacy of a flightweight F_2/N_2H_4 propulsion subsystem.

III. Description:

A small (700 kg) flightweight, pressure-fed propulsion subsystem with a thrust level of 2670N will be carried up to orbit, released, and fired. On-board instrumentation will be used to verify the test flight.

IV. Justification:

Reduce risk in order to obtain user acceptance of a new, higher-performance propulsion system for spacecraft propulsion.

I. Title:

Final Qualfication Test of Cesium Ion Engine

II. Objective:

To qualify a cesium ion engine as space proven hardware to make it available as a prime system component for spacecraft.

III. Description:

A cesium ion engine should be operated in space over a large number of on/off cycles, with appropriate data taken to verify proper operation.

IV. Justification:

A previous test of the cesium ion engine in space was satisfactory in all respects except for a fuel valve failure near the end of the planned test. The failure was attributed to zero-g effects so the qualification of the redesigned system must be tested in space to establish full validity.

4. OVERALL OBSERVATIONS AND SUMMARY OF PART II

1) The large majority, twelve (12) of the nineteen (19), items discussed and presented were classified in the first category: the special environment of space makes it the most reasonable way to perform the tests.

2) Of these candidates for space experiments, most can be implemented by small experiment packages - many of which could be carried on a single Spacelab flight. Exceptions wherein a large portion of the Spacelab capability may be needed are the following:

a) cryogenic propellant storage and transfer

b) deployment and handling of large structures for sails, concentrators, and photovoltaic panels

3) One entry in the first category (flight test of a composite engine) calls for the use of an airbreathing device either mounted external to the Shuttle or deployed from the cargo bay at high altitudes. The Orbiter would either be carried aloft by a 747 aircraft or launched vertically using SRB's smaller than Shuttle standard. This experiment would involve a major interaction with the Shuttle flight. Feasibility of such a test could not be ascertained with the information available to the Group.

4) Three candidate space experiments are listed in the second category. Justification is predicated on long-duration testing (up to years) in space-level vacuum being possibly less costly than extended use of the necessary vacuum facilities on the ground. Support of this justification would entail use of a very low-cost, free-flying platform, such as LDEF, which could be deposited in orbit by the Shuttle Orbiter and retrieved years later. Cost estimates for the extended use of a free-flying platform must be established in order to determine if these experiments would be

cost effective.

5) Four Experiments

a) Measurement of solid rocket motor thrust alignment

b) Qualification test of N_2H_4 Resistojet

c) Qualification of a F_2/N_2H_4 Propulsion System

d) Qualification of Cesium Ion Engines

were identified in the third category as being aids to gaining user acceptance.

6) The limited knowledge within the Group of the special requirements to be levied on experimenters intending to fly experiments on Spacelab or a free-flying platform may have inappropriately inhibited the ideas generated for the second and third categories of justification. Future solicitations for candidate space experiments should be accompanied by at least rough estimates of the projected requirements for space testing, including deliverables, safety constraints, preflight testing, and other items that impact the cost of utilizing the Shuttle as a test facility.

5. FORMS - DEFINITION OF TECHNOLOGY REQUIREMENTS

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-2

1. TECHNOLOGY REQUIREMENT (TITLE): Flight Test of an 8-cm Electron Bombardment Ion Thruster (Sphinx C) PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Demonstrate technology readiness and compatibility with spacecraft systems and functions of the 8-cm mercury ion thruster.

4. CURRENT STATE OF ART: Engineering model level hardware, based on extensive precursor development and demonstration is in the fabrication phase.

HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF EXPERIMENT:

Test of an electric propulsion stationkeeping system launched from a Shuttle-IUS combination or Delta booster. Performed as a companion experiment to Sphinx B. Cycle life performance equivalent to 10 years of stationkeeping to be demonstrated. The compatibility of thruster operation with spacecraft scientific, communication, and other functions to be verified.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. The values of specific impulse and thrust level are near optimum for a large class of geosynchronous satellites.

b. Geosynshronous satellites requiring precision north-south stationkeeping and attitude control.

c. As an example of mass savings, the use of mercury ion thrusters reduces the satellite control propulsion system from 21 to 10 percent of total spacecraft mass for a seven year mission with proportionally larger savings for longer missions.

d. This technology should be carried to an experimental demonstration on a free-flying satellite launched by a Shuttle-IUS combination or a Delta booster.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-2

1. **TECHNOLOGY REQUIREMENT(TITLE):** Flight Test of an 8-cm Electron Bombardment Ion Thruster (Sphinx C) **PAGE 2 OF 4**

7. **TECHNOLOGY OPTIONS:**

Test one thruster designed to operate at approximately twice the baseline thrust level to optimize system performance with a battery power source is possible.

Redesign of power processor or a separate experiment to take advantage of high voltage solar arrays is possible as the operating concept has been demonstrated.

8. **TECHNICAL PROBLEMS:**

1. Potential ion beam/spacecraft interactions for body mounted thrusters.

2. Possible structural/dynamic problems for end of the array mounted thrusters.

9. **POTENTIAL ALTERNATIVES:**

In the range of specific impulse greater than about 800 seconds, no alternate technology options to some form of electric propulsion presently exist or are proposed for auxiliary propulsion (Reference 1). Two other electric propulsion systems - electron bombardment thruster using cesium propellant and colloid thrusters - are presently under development. The former is generically quite similar to the mercury bombardment systems. The latter (colloid) operates at a specific impulse of about half that of the mercury systems.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

FTOP 502-22-11 "Auxiliary Propulsion Ion Thruster Technology"

EXPECTED UNPERTURBED LEVEL 5

11. **RELATED TECHNOLOGY REQUIREMENTS:**

Guidance, Navigation, and Control for low thrust propulsion systems.

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. E-2

1. TECHNOLOGY REQUIREMENT (TITLE): Flight Test of an 8 cm Electron Bombardment Ion Thruster (Sphinx C) — PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design																			
2. Fabrication																			
3. Test																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE		∇																
NUMBER OF LAUNCHES						1												

14. REFERENCES:

1. Outlook for Space A Forecast of Space Technology July 15, 1975

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

TITLE Flight Test of an 8-cm Electron Bombardment Ion Thruster (Sphinx C)

NO. E-2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Sphinx C Spacecraft

TEST DESCRIPTION: ALT. (max/min) 35,000 / 1,000 km, INCL. 18 deg, TIME 2,000 hr

BENEFIT OF SPACE TEST: Demonstrate ion thruster system operation in a space environment; investigate interactions of thruster generated plasma and high voltage surfaces.

EQUIPMENT: WEIGHT 216 kg, SIZE self- X con- X tained m, POWER > 150 kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. 0 OPERATIONS/DURATION ___ / ___

SPECIAL GROUND FACILITIES: Required ground facilities exist at LeRC

EXISTING: YES [X] NO [ ]

TEST CONFIDENCE 0.95

9. GROUND TEST OPTION TEST ARTICLE: 8-cm thruster, power processor, and gimbal system, and propellant tank.

TEST DESCRIPTION/REQUIREMENTS: Simulation test of ten-year attitude control system operation in space.

SPECIAL GROUND FACILITIES: Vacuum facilities with frozen mercury target.

EXISTING: YES [X] NO [ ]

GROUND TEST LIMITATIONS: Facility limitations do not allow accurate space simulation of plasma interface, evaluation of impact on communications or full demonstration of attitude control functions.

TEST CONFIDENCE 0.6

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ See reference (SUM OF PROGRAM COSTS $ ______)

*includes both Sphinx B and C

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

FT (TDR-2) 7/75

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-4

1. TECHNOLOGY REQUIREMENT (TITLE): Vibration Test of Solid Rocket Motor PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Determine effect of Shuttle acoustic and vibration environment on solid rocket kick motors from the response of a model motor and its propellant to this environment.

4. CURRENT STATE OF ART: Shake table approval tests; however, the specified vibration test spectrum poorly simulates the actual environment in the motor.

HAS BEEN CARRIED TO LEVEL 1

5. DESCRIPTION OF TECHNOLOGY

The tests now accomplished on flight motors are a series of simulated vibration environments. What is needed for improved design parameter values is knowledge of how a solid rocket motor and the viscoelastic propellant and insulation responds to the Shuttle environment. A model or representative subscale motor would be selected for this test.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Not selected yet.

b. All future missions which carry solid motors in the Shuttle: A2,3,4,5.

c. These results should provide for more reliable motors, and better performing designs.

d. Motor models should be instrumented internally to obtain data on the space Shuttle environment.

TO BE CARRIED TO LEVEL 4

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. E-4

1. **TECHNOLOGY REQUIREMENT(TITLE):** Vibration Test of Solid Rocket Motor — **PAGE 2 OF 4**

7. **TECHNOLOGY OPTIONS:**

8. **TECHNICAL PROBLEMS:**

Design of test models which will give meaningful data during the first test.

9. **POTENTIAL ALTERNATIVES:**

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 1

11. **RELATED TECHNOLOGY REQUIREMENTS:**

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. E-4

1. TECHNOLOGY REQUIREMENT (TITLE): Vibration Test of Solid Rocket Motor

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis																			
2. Design																			
3. Fabrication																			
4. Test							Δ												
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE							Δ											
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

TITLE Vibration Test of Solid Rocket Motor

NO. E-4

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION

TEST ARTICLE: Model Solid Rocket Motor and Propellant Grain and Insulation

TEST DESCRIPTION: ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

Carry model motor up and down and measure response inside of motor to Shuttle acoustic and vibration environment.

BENEFIT OF SPACE TEST: Will give environment the motor propellant grain actually feels and responds to.

EQUIPMENT: WEIGHT 100 kg, SIZE 1m X 1m X 1m m, POWER unknown kW

POINTING N/A STABILITY N/A DATA Vibration

ORIENTATION N/A CREW: NO. 0 OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: None

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE 75%

9. GROUND TEST OPTION

TEST ARTICLE: None

TEST DESCRIPTION/REQUIREMENTS:

SPECIAL GROUND FACILITIES:

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS:

TEST CONFIDENCE

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM

COST IMPACT PROBABILITY

COST RISK $ ______

FT (TDR-2) 7/75

DEFINITION OF TECHNOLOGY REQUIREMENT NO. F-6

1. TECHNOLOGY REQUIREMENT (TITLE): Propellant Management Device Design Parameters at zero -g PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Improve the analytical tools required to design propellant management device pressurant and outflow device.

4. CURRENT STATE OF ART: Only subscale devices can be tested for short times ($\leq$10S). Pressurant diffuser and outflow designs cannot be tested in this time with accuracy. HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

This technology experiment at zero -g would provide data to understand, model, and design pressurant diffusers; determine effects of contaminants on surface tension properties of liquid propellants; determine wicking properties of materials applicable to surface tension device; determine optimum outlet geometry for propellant tanks containing surface tension propellant management device.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Surface tension data is obviously needed if one is to design a propellant management device based on that physical property and to ensure positive phase separation.

b. Missions A 1, 3, 4, 5.

c. Based upon this advanced mission reliability and lifetime will be enhanced.

d. Represents a reliability upgrading by increasing confidence level of initial design.

TO BE CARRIED TO LEVEL 9

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. E-6

1. **TECHNOLOGY REQUIREMENT(TITLE):** Propellant Management Device Design Parameters at zero -g

7. **TECHNOLOGY OPTIONS:**

Through space experiments, an anticipated increase of approximately one order of magnitude in design information regarding surface tension device characteristics would result.

8. **TECHNICAL PROBLEMS:**

None

9. **POTENTIAL ALTERNATIVES:**

Continue current way of designing and accept the uncertainties and accept the use of less efficient designs.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

No flight tests are planned and left unperturbed, the technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 4

11. **RELATED TECHNOLOGY REQUIREMENTS:**

None

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. E-6

1. TECHNOLOGY REQUIREMENT (TITLE): Propellant Management Device & Design Parameters at zero -g

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis of Design			—	—															
2. Fabrication			—	—															
3. Ground checkout test					—	—													
4. Flight test & documentation						—	—												
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

TITLE Propellant Management Device Design Parameters at zero -g NO. E-6
PAGE 4 of 4

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: A modular package inside of Shuttle containing elements required to measure surface tension, pressurant/propellant interface.

TEST DESCRIPTION: ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

BENEFIT OF SPACE TEST: ______

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE 99%

9. GROUND TEST OPTION TEST ARTICLE: ______

TEST DESCRIPTION/REQUIREMENTS: ______

SPECIAL GROUND FACILITIES: No way to compete with space test capabilities.

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: Gravitational effects, short times in drop towers, and only linear disturbances.

TEST CONFIDENCE 75%

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

FT (TDR-2) 7/75

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-7

1. TECHNOLOGY REQUIREMENT (TITLE): Thruster Induced Back Contamination PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Determine back-contamination, in space conditions, from chemical and electric thruster in region beyond where current theories predict plume location.

4. CURRENT STATE OF ART: Low thrust (0.1 lbf) monopropellant hydrazine have been tested under laboratory conditions and some back-contamination has been measured.

HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

Currently, only small ≤ 5 lbf can be tested in the laboratory and the test facility itself imposes conditions such as back pressure and temperature induced by the plume. To fully map the plume and determine the back-contamination by placing both sensors and sensitive sample materials in the plume and back-flow region essentially a "zero" back pressure is needed. Thus, the critical parameter to be measured, plume flow, is limited by back pressures and thus the limiting variable must be eliminated.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Since thrusters of concern operate in space, it will be highly valuable to determine the plume map and hence the back-contamination under the actual conditions of "zero back pressure" as opposed to laboratory imposed constraints of 10^{-7} higher with larger thrust will adequately simulate actual operating conditions.

b. This experiment would benefit missions in classes A1, 3 through 6 and B.

c. The results of this experiment would provide the spacecraft or satellite designer with tools he does not currently have to locate critical sensors and/or surfaces away from the thruster so that they would not be adversely affected by the thruster during firing and to modify thruster designs to reduce back-contamination.

d. By determining the plume location under the real conditions of space, the accuracy of the current model would be improved by at least two orders of magnitude.

TO BE CARRIED TO LEVEL 8

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. E-7

1. **TECHNOLOGY REQUIREMENT(TITLE):** Thruster Induced Back Contamination

7. **TECHNOLOGY OPTIONS:**

Through the use of a space experiment, new plume models could be developed which would improve the prediction of plume location in far-flow field (≥ 90 from center line) of at least 2 orders of magnitude, and therefore, a significant increase in knowledge regarding contamination would result.

8. **TECHNICAL PROBLEMS:**

Virtually the same technology to determine plume flow in both near and far field and contamination measurements could be used in space as is used in laboratory testing. Therefore, no significant technical problems exist.

9. **POTENTIAL ALTERNATIVES:**

Continued ground tests with their inherent, limiting constraints.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

Current NASA technology is described in part of RTOP 506-24-24. The Air Force is also supporting the work. Both are ground tests and analyses only.

If NASA were to eliminate its resources, the technology would be slowed down by a factor of 50% on ground-testing. If the Air Force also did not support flight test, technology would not advance.

EXPECTED UNPERTURBED LEVEL 3

11. **RELATED TECHNOLOGY REQUIREMENTS:**

Real-time sensors would enhance test results.

DEFINITION OF TECHNOLOGY REQUIREMENT   NO. E-7

1. TECHNOLOGY REQUIREMENT (TITLE): Thruster Induced Back Contamination   PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis & Design																			
2. Fabrication																			
3. Ground Verification test																			
4. Flight test & verification																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE																	TOTAL
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

TITLE Thruster Induced Back Contamination

NO. E-7

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Modular propulsion system and sensors deployed outside the Shuttle.

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: Eliminate the limiting variable of back pressure. Require a vacuum of $\leq 10^{-12}$ torr.

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: Modular propulsion system with sensors provided inside the test chamber.

TEST DESCRIPTION/REQUIREMENTS: Thrusters and sensors mounted in test chambers. Thrust levels up to 500 lbf to be tested and measurements taken.

SPECIAL GROUND FACILITIES: Very large (on order of 100 ft. in diameter) liquid helium cooled, large pumping capacity vacuum chamber.

EXISTING: YES ☐ NO ☒

GROUND TEST LIMITATIONS: Size and type of thruster to be tested and back pressure.

TEST CONFIDENCE 80%

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FT (TDR-2) 7/75

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-8

1. TECHNOLOGY REQUIREMENT (TITLE): Supercritical Combustion Measurement in zero -g PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Establish supercritical droplet evaporation/combustion rates and flammability limits of liquid bipropellants.

4. CURRENT STATE OF ART: The above has only been attempted on the ground wherein the gravitational forces impose great experimental difficulty.

HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

Gravitational forces would be eliminated as a disturbing influence on the measurements of evaporation rates and flammability limits of liquid propellants in the critical region. At least one order of magnitude improvement in prediction of diffusion rate should be obtained over that obtained by current techniques for inputs to computerized combustion models for performance prediction.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Evaporation (vaporization) rate are critical inputs to performance modeling and have first order effects on results when working near the critical region.

b. A 1-6

c. With this information rocket engine design and testing could be reduced, resulting in a cost savings.

d. Needs to be carried to a point wherein the above input is not required from engine tests.

TO BE CARRIED TO LEVEL 8

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. E-8

1. **TECHNOLOGY REQUIREMENT (TITLE):** Supercritical Combustion Measurements in zero -g

7. **TECHNOLOGY OPTIONS:**

The improvements in measurements of evaporation rates and flammability limits are expected to increase by at least one order of magnitude which in turn will increase accuracy of performance prediction at least 25%. This improvement will reduce the number of hardware tests to be conducted by at least 30%.

8. **TECHNICAL PROBLEMS:**

The development of the apparatus.

9. **POTENTIAL ALTERNATIVES:**

Continue ground testings with their inherent inaccuracies.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

For all intents and purposes there is no on-going technology effort, even ground based, because of the drastic funding reduction in combustion research.

Without NASA resources, technology will not advance.

EXPECTED UNPERTURBED LEVEL 2

11. **RELATED TECHNOLOGY REQUIREMENTS:**

None

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-8

1. TECHNOLOGY REQUIREMENT (TITLE): Supercritical Combustion Measurements in zero -g

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design																			
2. Fabrication																			
3. Ground Test Checkout																			
4. Flight Test & Documentation																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

TITLE Combustion Measurements in zero -g

NO. E-8

PAGE 4 of 4

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Package containing provision for gas analysis, flame temperature, spectroscopy measurements, and high speed photography.

TEST DESCRIPTION: ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

BENEFIT OF SPACE TEST: Eliminate gravitations effects which cloud the measurements of diffusion rates.

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: None

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE 95%

9. GROUND TEST OPTION TEST ARTICLE: Essentially same as above, but smaller and/or separate packages.

TEST DESCRIPTION/REQUIREMENTS: ______

SPECIAL GROUND FACILITIES: Drop tower

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: very short time duration ($\leq$ 10s)

TEST CONFIDENCE 50%

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

FT (TDR-2) 7/75

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. E-9

1. TECHNOLOGY REQUIREMENT (TITLE): Pulse Characteristics of Small Thrusters — PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Improve the resolution of thruster impulse bit measurement.

4. CURRENT STATE OF ART: Numerous types of thrust balances are currently being used for measuring thrust in the range of 0.5 lb to 1.0 lb. All have problems of environmental noise & frequency. HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY

The experiment is to refine the measurement of impulse bit shapes and create a "standard" engine for standardization of measurements on ground-based thrust balances. It is accomplished by firing thruster (s) on a free-flying platform and taking measurements from an inertial reference.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Increased precision in the measurement of small impulse bit profiles is needed to take advantage of the potential precision inherent in present sensor control logic technology.

b. All on orbit operational spacecraft utilizing expanding gas thrusters for attitude control would benefit.

c. All spacecraft utilizing attitude control thrusters in the low millipound thrust range and below would benefit from a more accurate knowledge of impulse bit characteristics from the standpoint of precise matching of force to control requirement and the related fuel savings.

Resolution of impulse bit profile in ground test is limited by environmental noise and ground related design weaknesses of the thrust balance itself.

d. The data are compared to ground test data to permit better interpretation of the latter and to develop filtration/mathematical techniques applicable to other thrusters.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. E-9

1. **TECHNOLOGY REQUIREMENT(TITLE):** Pulse Characteristics of Small Thrusters **PAGE 2 OF 4**

7. **TECHNOLOGY OPTIONS:**

8. **TECHNICAL PROBLEMS:**

   1. An inertial reference of sufficient stiffness and sensitivity.
   2. Noise introduced by propellant valve operation.

9. **POTENTIAL ALTERNATIVES:**

   None

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

    Technology will not advance without NASA resources.

    EXPECTED UNPERTURBED LEVEL 5

11. **RELATED TECHNOLOGY REQUIREMENTS:**

    Inertial reference.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. E-9

1. TECHNOLOGY REQUIREMENT (TITLE): Pulse Characteristics of Small Thrusters PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design																			
2. Fabrication																			
3. Test																			
4. Flight																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

TITLE Pulse Characteristics of Small Thrusters

NO. E-9

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION

TEST ARTICLE: Thrust Measurement System

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL ____ deg, TIME ____ hr

Measure impulse bit thrust profiles on an inertially referenced platform.

BENEFIT OF SPACE TEST: Elimination of environmentally introduced noise in the measurements.

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: None

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE 70%

9. GROUND TEST OPTION

TEST ARTICLE: ____

TEST DESCRIPTION/REQUIREMENTS: None known for very small impulse bit systems.

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM

DOMINANT RISK/TECH PROBLEM	COST IMPACT	PROBABILITY

COST RISK $ ____

FT (TDR-2) 7/75

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-10

1. TECHNOLOGY REQUIREMENT (TITLE): Flight Test of Composite Engine PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Verification test of large scale composite engine such as ejector ramjet using Shuttle Orbiter as a flight test vehicle.

4. CURRENT STATE OF ART: Subscale ground tests to hypersonic engine (HPE) have been completed at Lewis and tests of ramjets of small size have been done at Marquardt. HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

Flight tests of full scale composite engines suitable for use on an HTOHL two-stage fully reusable Shuttle-type vehicle. Facilities do not exist for ground test of large composite engines at high Mach numbers because of the large flow-rate of heated air needed. Shuttle Orbiter could be employed as a flying test bed for flight tests at cruise mode conditions similar to the planned X-24 program.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. N/A

b. Applications of large composite engines are to HTOHL Shuttle-type vehicles for low cost transport of payloads to low earth orbit.

c. Flight test is needed to provide verification of the complete composite engine system at proper operating conditions of Mach number and inlet air conditions.

d. Flight verification test of full scale composite engine using Shuttle Orbiter stage as flying test bed. Test cannot be defined precisely until engine type and configuration are selected. May require a dedicated Orbiter with considerable modification for launch using carrier aircraft 747 or modified booster (SPB) and ET to obtain proper altitude and speed to start composite engine.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-10

1. TECHNOLOGY REQUIREMENT(TITLE): Flight Test of Composite Engine PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Many options exist in design of the composite engine (air turborocket, ramjet, scramjet, etc.) and the integration of the engine with Orbiter for flight test. Simplest arrangement would be storage of the engine within the cargo bay and deployment at altitude. This may not be feasible because of inlet design, problems of deploying engine, and making Orbiter aerodynamically clean and stable. Alternate approach would be modification of Orbiter to integrate engine on bottom of vehicle.

8. TECHNICAL PROBLEMS:

Problems involved include modification of Shuttle for launch and for integration of engine with Orbiter vehicle. Also, ability of Orbiter to withstand the aerodynamic heating for cruise flight at high Mach number and control of the vehicle are important problems.

9. POTENTIAL ALTERNATIVES:

Alternative to flight test is ground test of full scale composite engine. No facilities exist presently that are capable of supplying the large quanities of air heated to high temperature and the capital investment would be quite large for such a facility.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Unperturbed Program - Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 4

11. RELATED TECHNOLOGY REQUIREMENTS:

Comprehensive technology program needed on composite engines to bring them to the level of maturity necessary before flight testing will be required. This program is described under Propulsion - Definition of Technology Requirement number IA (1)K.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. E-10

1. TECHNOLOGY REQUIREMENT (TITLE): Flight Test of Composite Engine PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Engine Design/Fabrication																			
2. Orbiter Analyses, Redesign, Modification																			
3. Flight Test Program																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

TITLE Flight Test of Composite Engine **NO.** E-10

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION **TEST ARTICLE:** Shuttle modified as needed for flight test of full scale composite (rocket/air breather) engine at proper conditions of altitude and mach number.

TEST DESCRIPTION: ALT. (max/min) ____/____ km, INCL. ____ deg, TIME ____ hr

Orbiter with composite engine for test would be carried aloft by 747 aircraft or launched by smaller SRB's to obtain proper altitude and Mach number.

BENEFIT OF SPACE TEST: Large scale composite engine can be tested at proper conditions to provide full verification of performance and controllability.

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____/____

SPECIAL GROUND FACILITIES: Launch pad if vertical take off mode employed or runway for horizontal takeoff if 747 aircraft to carry Orbiter aloft. **EXISTING:** YES [X] NO [ ]

TEST CONFIDENCE ____

9. GROUND TEST OPTION **TEST ARTICLE:** Full scale composite engine, such as ramjet, scramjet, or air turborocket.

TEST DESCRIPTION/REQUIREMENTS: Long duration tests at full thrust; throttling tests start-up and shutdown tests.

SPECIAL GROUND FACILITIES: Test facility must provide large flow rate of air heated to high temperatures to simulate proper conditions of Mach number and altitude **EXISTING:** YES [ ] NO [X]

GROUND TEST LIMITATIONS: No facilities presently exist for full scale composite engine test. Investment cost would be very high for such a facility.

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FT (TDR-2) 7/75

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-12

1. TECHNOLOGY REQUIREMENT (TITLE): Sublimation Properties of Solidified Propellants PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Better prediction of sublimation rates and heat transfer in the absence of gravity effects.

4. CURRENT STATE OF ART: Fragmentary data obtained from laboratory experiment.

HAS BEEN CARRIED TO LEVEL 1

5. DESCRIPTION OF TECHNOLOGY

Appropriate tanks containing candidate propellants cooled to the solid state are tested in the laboratory to establish baseline performance for comparison with subsequent similar tests carried out in the zero -g space environment. Typical propellants to be considered are methane and ammonia.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Gravitational effects of convection and forced contact of the solid with the container are not succeptable to reasonable calculation when attempting to extropolate to calculation of heat transfer/sublimation rates in zero -g so experimental data in that environment is needed for design calculations.

b. The primary missions to which this concept is addressed are earth orbital spacecraft with electromagnetic spectrum sensing capabilities.

c. One of the simplest sensor cooling methods proposed by designers, uses a subliming frozen gas or liquid. The sublimed gas could serve as a propellant for the attitude control system thus permitting a combined function system with the attendant simplification of S/C design, reduction of total mass on board, and attendant cost savings.

d. Sufficient data on the storage/sublimation properties of candidate propellants must be obtained from a testing in space to permit concept evaluation and system design.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. E-12

1. **TECHNOLOGY REQUIREMENT(TITLE):** Sublimation Properties of Solidified Propellants **PAGE 2 OF 4**

7. **TECHNOLOGY OPTIONS:**

8. **TECHNICAL PROBLEMS:**

Establishing a valid scaling model from limited data. Technique for measuring very low sublimation rates may be a problem.

9. **POTENTIAL ALTERNATIVES:**

Overdesign systems utilizing the principle and provide commandable auxiliary heat input to compensate.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 1

11. **RELATED TECHNOLOGY REQUIREMENTS:**

None

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. E-12

1. TECHNOLOGY REQUIREMENT (TITLE): Sublimation Properties of Solidified Propellants — PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/design																			
2. Fabrication																			
3. Ground test																			
4. Space test																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

TITLE Sublimation Properties of Solidified Propellants NO. E-12

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Container of solidified propellants

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

Measure sublimation characteristics of selected solidified propellants in zero-g environment.

BENEFIT OF SPACE TEST: Elimination of gravity effects on heat transfer and mass distribution in the tank.

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: Experiment GSE required.

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: ____

TEST DESCRIPTION/REQUIREMENTS: Information needed is directly linked to space environment so ground test option does not exist.

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FT (TDR-2) 7/75

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-13

1. TECHNOLOGY REQUIREMENT (TITLE): Flight Test with Solar Electric Propulsion Thrust Subsystem PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Verify thrust subsystem performance, and characterize the interfaces, lifetime, and reliability of a solar electric primary propulsion system.

4. CURRENT STATE OF ART: Thruster developed to engineering model status and other thrust subsystem elements developed to at least functional demonstration status.

HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY

The first flight might be either a long term test on a low cost free-flying test bed launched from the Shuttle or a dedicated satellite launched to out-of-the-ecliptic from a Shuttle-IUS. The thrust subsystem would contain 30 cm mercury bombardment thrusters, power processors, thrust vectoring mechanisms, electrically isolated propellant supply and distribution system, thrust subsystem controller, solar array, attitude control system, and appropriate scientific and engineering data systems.

The test bed option would serve to define thrust subsystem performance parameters, interfaces, and lifetime and reliability. The free-flying satellite option would accomplish these engineering and technology goals as well as obtain scientific data.

P/I REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a) The value of I_{sp} of 3000 seconds is near optimum for this and a large set of other missions based on projected values of the specific mass of solar arrays and other thrust subsystem elements. The use of mercury propellant provide maximum thrust to power ratios of importance for power limited, performance critical missions.

b) In general, high energy missions such as comet rendezvous, out-of-ecliptic, low earth to geosynchronous orbit transportation and on-orbit operations of very large space systems are strongly benefited by the use of high specific impulse, high performance, propulsion systems.

c) With reasonable payloads, use of electric propulsion extends the achievable heliocentric inclination from about 50° to 90°, can provide for accurate trajectory shaping, strongly increase payloads for high energy missions, and relax launch window opportunity constraints.

d) This technology should be demonstrated via an out-of-ecliptic mission launched from an early Shuttle-IUS flight or on a low cost test bed in near earth environment.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-13

1. **TECHNOLOGY REQUIREMENT(TITLE):** Flight Test with Solar Electric Propulsion Thrust Subsystem **PAGE 2 OF 4**

7. **TECHNOLOGY OPTIONS:**

Variation of the specific impulse within a factor of two could be provided with little change in baseline technology. Operation of the high voltage and discharge power supplies directly from the array (without power conditioning) could lead to a significant (≈ 15 percent) reduction in thrust subsystem mass. The potential exists for the operation of the thrust subsystem from advanced power sources, such as nuclear thermionic, with no change to baseline technology except in the power processing elements. The modular concept utilized throughout the thrust subsystem allows for large increases in system power without major technology impact.

8. **TECHNICAL PROBLEMS:**

1) The target of 12 kg/kwe (exclusive of power system) is expected to be difficult to achieve.

2) The control and possible interactions of the solar array with ambient plasma are potential difficulties.

9. **POTENTIAL ALTERNATIVES:**

1) Use of electron-bombardment thrusters using light fuels instead of mercury.

2) Use of magnetoplasmadynamic (MPD) thrusters at reduced specific impulse.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

RTOP 506-22-30 Prime Propulsion Ion Thruster Technology

No experiment would be expected without NASA resources.

EXPECTED UNPERTURBED LEVEL __

11. **RELATED TECHNOLOGY REQUIREMENTS:**

Guidance, Navigation, and Control of Low Thrust Systems.

Structural Dynamics of large, flexible spacecraft.

Thermal control of large power systems.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. E-13

1. TECHNOLOGY REQUIREMENT (TITLE): Flight Test with Solar Electric Propulsion Thrust Subsystem

PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design																			
2. Fabrication																			
3. Test																			
4. Documentation																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

1. Outlook for Space. A Forecast of Space Technology. July 15, 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

TITLE Flight Test with Solar Electric Propulsion Thrust Subsystem NO. E-13

PAGE 4 of 4

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Free-flying solar electric propulsion thrust subsystem.

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME 15,000 hr

BENEFIT OF SPACE TEST: Verify ground based performance and interface measurements and provide baseline for extension of electric propulsion.

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER 12-30 kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE 0.95

9. GROUND TEST OPTION TEST ARTICLE: Thrust subsystem without solar array system or functioning attitude control system.

TEST DESCRIPTION/REQUIREMENTS: Integration and life test of thrust subsystem.

SPECIAL GROUND FACILITIES: Very large vacuum facility with mercury (or other high vapor pressure material) target for long term testing.

EXISTING: YES ☐ NO ☒

GROUND TEST LIMITATIONS: Cannot test system with deployed solar array. Cannot accurately simulate GN C operation or all thrust subsystem interfaces.

TEST CONFIDEN 0.75

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

Solar Array Control and Interactions

COST RISK $ ____

FT (1DR 2) 7/75

DEFINITION OF TECHNOLOGY REQUIREMENT NO. F-14

1. TECHNOLOGY REQUIREMENT (TITLE): Flight Tests of Low Molecular Weight Propellant Bombardment Thruster PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Verify performance parameters, interfaces, and lifetime of bombardment thrusters. Verify critical technology for potential application to MPD thruster systems.

4. CURRENT STATE OF ART: Low molecular weight propellant thruster operation demonstrated with several thruster types.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF EXPERIMENT

First flight would be a pallet mounted light fuel bombardment thruster test. Prototype thruster, propellant supply and distribution system, thrust vector mechanisms, and thrust control system would be utilized. Thruster performance parameters and interfaces would be characterized by normal spacelab test.

A subsequent test with a free-flying low cost test bed launched from the shuttle would be used to verify critical element lifetime and provide input for MPD thruster system requirements.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Selection of thruster design for operation between about 4,000 and 10,000 seconds specific impulse would satisfy the optimal system requirements for both low earth orbit to geosynchronous transportation and geosynchronous on-orbit operations of very large space structures. Propellant supply system and thrust vectoring equipment would be selected to be compatible with nuclear power system and/or MPD thruster system requirements.

b. Low earth to geosynchronous transportation and on-orbit operation of very large space system.

c. As an example, the use of a 4,000 second specific impulse propulsion system at projected efficiencies should increase the shuttle earth to geosynchronous payload capability by more than a factor of four.

d. This technology should be carried to an experimental demonstration on an early shuttle flight followed by a free-flying experiment also launched from shuttle.

TO BE CARRIED TO LEVEL 7

1. **TECHNOLOGY REQUIREMENT(TITLE):** Flight Test of Low Molecular Weight Propellant Bombardment Thruster Subsystem

7. **TECHNOLOGY OPTIONS:**

First test options could include variation of power source characteristics to simulate a nuclear power system and the extension of the thruster system on long booms to obtain data relevant to the control of large flexible space structures. Operation on various light fuels would allow simulation of the use of indigenous space or planetary materials.

8. **TECHNICAL PROBLEMS:**

1. Achievement of a high efficiency, long life, light fuel thruster would require some redesign of the baseline mercury bombardment systems.

2. Development of a light weight propellant supply and distribution system.

9. **POTENTIAL ALTERNATIVES:**

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

RTOP 506-22-40 "Ion Thruster Research"

No flight would occur without NASA resources.

EXPECTED UNPERTURBED LEVEL 4

11. **RELATED TECHNOLOGY REQUIREMENTS:**

Guidance, Navigation, and Control of large flexible spacecraft.

Structural dynamics of large flexible spacecraft.

Advanced thermal control and power distribution technology.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. E-14

1. TECHNOLOGY REQUIREMENT (TITLE): Flight Test of Low Molecular Weight Propellant Bombardment Thruster Subsystem

PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design																			
2. Fabrication																			
3. Test																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

TITLE Flight Test of a Low Molecular Weight Propellant Bombardment Thruster Subsystem

NO. E-14

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Flight test of low molecular weight propellant bombardment thruster subsystem.

TEST DESCRIPTION: ALT. (max/min) ____/____ km, INCL. ____ deg, TIME ____ hr

Subsystem test on a low cost test bed at shuttle altitude.

BENEFIT OF SPACE TEST: Would allow accurate definitions of performance parameters, interfaces, and system lifetime.

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____/____

SPECIAL GROUND FACILITIES: Very large space simulation chambers.

EXISTING: YES [X] NO [ ]

TEST CONFIDENCE 0.9

9. GROUND TEST OPTION TEST ARTICLE: ____

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES [ ] NO [ ]

GROUND TEST LIMITATIONS: Very large cost and difficulty in simulation of space vacuum with light propellants. Impossible to simulate GN and C requirements in ground tests.

TEST CONFIDENCE 0.6

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

F 1 (1DR 2) 7/75

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-15

1. TECHNOLOGY REQUIREMENT (TITLE): Space Storability of Solid Rocket Motors PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: To demonstrate the space storability of solid rocket motors.

4. CURRENT STATE OF ART: Short time tests under vacuum or simulated high dose rate have been accomplished; actual motors have never been exposed for long durations to both.

HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

Solid propellant rocket motors have been stored and used successfully after long storage times on earth, but have not been used after long time exposure in space. There is currently some doubt on the reliability of a unit after such exposure. A demonstration needs to be accomplished so that limits of exposure can be defined; flight type units could then be successfully stored in space.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Trips to the outer planets require up to 3 years and very reliable propulsion maneuvers for retro into orbit or landing; thus, extended exposure data needs to be provided.

b. On-orbit operations at the planets, extraterrestial landing and take off, and for shorter periods low earth orbit to geosynchronous orbit.

c. The result of these tests will give confidence that solid motors will perform as-designed after space exposure.

d. Flight design unit and samples should be carried into space and then inspected after various exposure times.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-15

1. TECHNOLOGY REQUIREMENT(TITLE): Space Storability of Solid Rocket Motors PAGE 2 OF 4

7. TECHNOLOGY OPTIONS:

The minimum time should be 2 weeks, with severe exposure conditions and it is necessary to have a 1 to 2 year exposure. A 5 year or longer exposure would even be better with samples being returned periodically. The areas of greatest interest are: propellant mechanical properties, bond strength, and ignition. The reaction of ammonium perchlorate to nuclear radiation at low dosage for long times could be correlated with existing data performed for short time periods.

8. TECHNICAL PROBLEMS:

9. POTENTIAL ALTERNATIVES:

Ground test in dedicated facility which can provide high vacuum, temperature, and nuclear radiation.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 2

11. RELATED TECHNOLOGY REQUIREMENTS:

This could be flown on the LDEF.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. E-15

1. TECHNOLOGY REQUIREMENT (TITLE): Space Storability of Solid Rocket Motors — PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Design of Experiment																			
2. Fabrication																			
3. Exposure																			
4. Test Results							*		*										
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE																TOTAL
NUMBER OF LAUNCHES																

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

TITLE Space Storability of Solid Rocket Motors

NO. E-15

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Solid Rocket Motor and Samples

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

Store samples in space for at least three years. Bring back some samples periodically for ground inspection and test; some tests may be done in orbit.

BENEFIT OF SPACE TEST: Provide confidence that motor as designed can withstand space environments.

EQUIPMENT: WEIGHT 100 kg, SIZE 1m X 1m X 1m m, POWER 0 kW

POINTING ____ STABILITY none DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: Laboratory

EXISTING: YES [X] NO [ ]

TEST CONFIDENCE 75%

9. GROUND TEST OPTION TEST ARTICLE: Solid Rocket Motor and Test Specimens

TEST DESCRIPTION/REQUIREMENTS: Expose simultaneously to thermal, nuclear radiation and low vacuum a motor with live propellant and propellant samples.

SPECIAL GROUND FACILITIES: Dedicated low vacuum and radiation source with thermal cycling facility for hazardous materials over long periods.

EXISTING: YES [ ] NO [X]

GROUND TEST LIMITATIONS: Exposure is difficult to simulate.

TEST CONFIDENCE 25%

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FT (TDR 2) 7-75

1. **TECHNOLOGY REQUIREMENT(TITLE):** Measurement of Solid Rocket Motor Thrust Alignments

7. **TECHNOLOGY OPTIONS:**

The results of these tests should permit the control requirements to be reduced by a factor of ten from knowledge of parameters and factors which contribute to misalignment of the thrust vector, an accurate measurement of the parameters, and spacecraft balance.

8. **TECHNICAL PROBLEMS:**

Space measurements to accuracy required. Assumes that cold gas and rocket motor hot gas flows can be modeled for correlation of data and analysis.

9. **POTENTIAL ALTERNATIVES:**

Markedly better ground test equipment (thrust stand) and facilities which do not now exist.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 2

11. **RELATED TECHNOLOGY REQUIREMENTS:**

PRECEDING PAGE BLANK NOT FILMED

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-16

1. TECHNOLOGY REQUIREMENT (TITLE): Measurement of Solid Rocket Motor Thruster Alignment

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis																			
2. Experimental Design																			
3. Fabrication																			
4. Test																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

TITLE Measurement of Solid Rocket Motor Thrust Alignment

NO. E-16

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Solid Motor Model or Simulator, Instrumentation and Cold Gas Flow System.

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

Zero-g and space vacuum.

BENEFIT OF SPACE TEST: Determine the misalignment of thrust vector to greater accuracy and provide understanding and correction to spacecraft in space.

EQUIPMENT: WEIGHT 500 kg, SIZE 1m X 1m X 1m m, POWER ____ kW

POINTING any STABILITY any DATA movements

ORIENTATION any CREW: NO. 0 OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE 80%

9. GROUND TEST OPTION TEST ARTICLE: Very difficult without zero-g and high vacuum; facility and equipment do not now exist.

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

T (TDR 2) 7/75

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-17

1. TECHNOLOGY REQUIREMENT (TITLE): Final Qualification Test of Hydrazine Resistojet PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: To demonstrate flight readiness of hydrazine resistojets for use in space.

4. CURRENT STATE OF ART: Hydrazine resistojets have been built and tested but not flown.

HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY

A small hydrazine resistojet in the 30 to 100 millipound thrust range combined with an appropriate feed system and instrumentation is flown in space and operated over a spectrum of pulse lengths and heater powers.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. More reliable thrusters with improved performance are needed for future NASA missions. The hydrazine resistojet is such a device but an orbital flight is necessary to qualify the device for flight readiness acceptance.

b. This advancement is applicable to on-orbit operations.

c. Attitude control systems are increasingly required to perform reliably and repeatedly for longer periods of time with more operating cycles. The hydrazine resistojet has no catalyst bed and so has the potential for very high operating cycle life with highly repeatable pulses. The specific impulse is slightly higher than the equivalent catalyst bed thruster. The minimum impulse bit achievable approaches the size obtainable with cold gas which tends to save fuel and/or give finer attitude control.

d. The thruster must be carried through a complete component test under flight operation conditions.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. E-17

1. **TECHNOLOGY REQUIREMENT(TITLE):** ~~Final Qualification Test of Hydrazine Resistojet~~ **PAGE 2 OF** 4

7. **TECHNOLOGY OPTIONS:**

None

8. **TECHNICAL PROBLEMS:**

Electrical heater life is a potential problem on extremely long missions.

9. **POTENTIAL ALTERNATIVES:**

1. Incorporate the thruster in payloads based on ground testing only. This is highly unlikely.

2. Fly is as an experiment on some unspecified s/c launched on a Delta rocket.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 5

11. **RELATED TECHNOLOGY REQUIREMENTS:**

None

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. E-17

1. TECHNOLOGY REQUIREMENT (TITLE): Final Qualification Test of Hydrazine Resistojet

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Design			—	—															
2. Fabrication				—	—														
3. Test					—														
4. Flight Readiness						o													
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Hydrazine Resistojet

TEST DESCRIPTION: ALT. (max/min) no max / low earth km, INCL. N/A deg, TIME N/A hr
Operate a hydrazine resistojet over a range of duty cycles and power inputs.

BENEFIT OF SPACE TEST: Qualification of a new type of thruster as space proven hardware to make it available as a prime system component for spacecraft.

EQUIPMENT: WEIGHT 5 kg, SIZE .4 X .4 X .4 m, POWER .005-.030 kW
POINTING N/A STABILITY N/A DATA pressure, temperature
ORIENTATION out CREW: NO. 1 OPERATIONS/DURATION 3-12 16 hr. max

SPECIAL GROUND FACILITIES: N_2H_4 fueling

EXISTING: YES [X] NO [ ]
TEST CONFIDENCE 90%

9. GROUND TEST OPTION TEST ARTICLE:

TEST DESCRIPTION/REQUIREMENTS: Since the object of the test is actual operation in space, there is no ground test option.

SPECIAL GROUND FACILITIES:

EXISTING: YES [ ] NO [ ]

GROUND TEST LIMITATIONS:

TEST CONFIDENCE

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ (SUM OF PROGRAM COSTS $)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $

FT (TDR 2) 7/75

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-18

1. TECHNOLOGY REQUIREMENT (TITLE): Final Qualification of an F_2/N_2H_4 Propulsion Subsystem PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide final verification of design adequacy of a flight-weight F_2/N_2H_4 propulsion subsystem.

4. CURRENT STATE OF ART: a bread-board FLOX/MMH propulsion subsystem has been tested in a vacuum facility.

HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

An F_2/N_2H_4 propulsion subsystem will be carried into orbit by Shuttle released on a stable platform, and fired. It will carry appropriate instrumentation to verify operational integrity.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. In high energy mission, specific impulse becomes a very sensitive parameter.

b. Missions A 4 and 5.

c. The technology itself will improve payload performance, increase V, or shorten trip time. This experiment will reduce risk.

d. The subsystem should be fully flight-qualified to convince the potential user that is it a viable option and uncover unforeseen. problems in space may be revealed.

TO BE CARRIED TO LEVEL 8

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-18

1. TECHNOLOGY REQUIREMENT(TITLE): Final Qualification of an F_2/N_2H_4 Propulsion Subsystem

7. TECHNOLOGY OPTIONS:

The specific impulse in the driver for this technology. A minimum specific impulse of 370 lbf-sec/lbm is required. Based upon typical outer planet orbiter missions, payload will vary decrease 3-5 lbm per unit of Isp reduction.

8. TECHNICAL PROBLEMS:

LF2 handling, materials capability.

9. POTENTIAL ALTERNATIVES:

Earth-storable propulsion systems with their inherently lower performance.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

If funded at an increased level, a flight-weight propulsion subsystem will be ready by 1980 (RTOP 506-24-26).

The technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 3

11. RELATED TECHNOLOGY REQUIREMENTS:

None

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. E-18

1. TECHNOLOGY REQUIREMENT (TITLE): Final Qualification of an F_2/N_2H_4 Propulsion Subsystem

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Fabrication							—	—											
2. Ground Test Checkout								—	—										
3. Flight Test and Documents									—	—									
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

TITLE Final Qualification of an F_2/N_2H_4 Propulsion System

NO. E-18

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: F_2/N_2H_4 Propulsion System

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: Risk Reduction

EQUIPMENT: WEIGHT 1,000 kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: F_2 propellant loading facility at cape.

EXISTING: YES ☐ NO ☒

TEST CONFIDENCE 99%

9. GROUND TEST OPTION TEST ARTICLE: Flight-weight F_2/N_2H_4 Propulsion Subsystem

TEST DESCRIPTION/REQUIREMENTS: Qualify F_2/N_2H_4 system by ground qualification program just as is done for earth-storable systems currently in use.

SPECIAL GROUND FACILITIES: Attitude test facility.

EXISTING: YES ☒ NO ☐

GROUND TEST LIMITATIONS: Less convincing to projects in accepting use of an untried technology.

TEST CONFIDENCE 80%

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

LI (TDR 2) 7 75

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-19

1. TECHNOLOGY REQUIREMENT (TITLE): Final Qualification Test of Cesium Ion Engine PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Propulsion

3. OBJECTIVE/ADVANCEMENT REQUIRED: To qualify a cesium ion engine as space proven hardware to make it available as a prime system component for spacecraft.

4. CURRENT STATE OF ART: Has been flown as an experiment but was not completely successful.

HAS BEEN CARRIED TO LEVEL 7

5. DESCRIPTION OF TECHNOLOGY

A cesium ion engine thruster system is flown in space and operated through a number of on/off cycles.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. The previous flight of this engine satisfied all objectives except for a valve failure due to zero-g effects during an on/off cycle. This has been corrected by redesign. An orbital flight is necessary to qualify the new design for flight readiness acceptance.

b. Payloads in earth orbit benefit from this technology.

c. The projected NASA program shows the need for high specific impulse, low thrust engines for use on orbital spacecraft. The cesium ion engine is such a device.

d. An orbital flight verifying design adequacy of a thruster system module will fully mature the technology for application to s/c systems.

TO BE CARRIED TO LEVEL 9

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-19

1. TECHNOLOGY REQUIREMENT(TITLE): Final Qualification Test of Cesium Ion Engine

7. TECHNOLOGY OPTIONS:

8. TECHNICAL PROBLEMS:

The redesigned fuel feed valve may still not function in zero-g.

9. POTENTIAL ALTERNATIVES:

None

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Technology will not advance without NASA resources.

EXPECTED UNPERTURBED LEVEL 7

11. RELATED TECHNOLOGY REQUIREMENTS:

None

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E-19

1. TECHNOLOGY REQUIREMENT (TITLE): Final Qualification Test of Cesium Ion Engine PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Ground Testing																			
2. Flight Packaging																			
3. Flight Operation																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

TITLE Final Qualification Test of Cesium Ion Engine NO. E-19

PAGE 4 of 4

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Cesium Ion Engine

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

Operate engine in space over a number of on/off cycles and preferably return to earth for analysis.

BENEFIT OF SPACE TEST: Faulty operation on previous flight was attributed to zero-g effects. Retest in zero-g needed for full confidence in redesign.

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: None needed.

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE 75%

9. GROUND TEST OPTION TEST ARTICLE: Since the object of the test is to verify operation in zero-g, there is no ground test option.

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FT (TDR 2) 7/75

N A S A

Office of Aeronautics and Space Technology

Summer Workshop

August 3 through 16, 1975

Conducted at Madison College, Harrisonburg, Virginia

Final Report

PROPULSION TECHNOLOGY PANEL
(part I)
Volume V of XI

OAST SPACE TECHNOLOGY
WORKSHOP

August, 1975

Propulsion Technology Group Report

PART I

ADVANCED TECHNOLOGY REQUIREMENTS

C3

OAST Space Technology Workshop

PROPULSION TECHNOLOGY PANEL

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Summary

Three major cost reduction thrusts were developed as directions for advanced propulsion technology development. They are:

1. Reduce cost of transport from earth to low earth orbit from 500 $/kg to 50 $/kg
2. Reduce cost of transport from earth to geosynchronous orbit from $3000/kg to 500 $/kg
3. Reduce cost of transport from earth to the outer reaches of the planet from $3x10^6$ $/kg to 3000 $/kg.

The relative importance of each of the three thrusts depends to a large extent on the specific missions ultimately given priority by NASA. Consequently, the group has identified technology areas according to the type mission which would drive research in that area. The present state of development of the particular technology has been assessed and it has been identified with at least one of the three major thrusts. The accompanying Table of Advanced technology Requirements represents a summary of the findings of the Propulsion Technology Working Group.

Code	Current Status	Readiness Date
A	In Use	Prior to 1975
B	Near Term	1975-1985
C	Far Term	1985-2000
D	Conceptual	Post 2000

Candidate payload experiments were also identified which could be advantageously carried out in near-earth space using the Shuttle Orbiter, its payload bay, the Spacelab and/or some free-flying device that might be used for long duration testing. The nineteen experiments identified were grouped in three categories according to the principal rationale for carrying out experiments in space:

I. The special characteristics of the space environment makes testing from the Shuttle Orbiter and its related equipment the only, or most reasonable, approach for obtaining data.

II. Testing in space is expected to be more cost-effective than carrying out similar tests on earth.

III. Tests in near-earth space provide a very close approximation to the conditions to be encountered by operating systems and as such may reveal unforseen problems of operations in space or may otherwise provide risk reduction for the

hardware design. In this way space testing will aid in giving user acceptance of a new technology.

The accompanying table of Candidate Space Experimental Payloads summarize the suggested propulsion experiments .

TABLE OF CANDIDATE SPACE EXPERIMENTAL PAYLOADS

Space Payload Justification Categories
I. Space Environment Essential
II. Space Experiment Most Cost Effective
III. Space Demonstration to Reduce Risk

No.	Title	Justification Category
E1	Spacecraft Charging and High Voltage Interactions with Plasma (submitted to Power Technology Group)	I
E2	Flight Test of 8-cm Bombardment Thruster	I
E3	High Temperature Plasma Core Reactor Fluid Mechanics (low-g) (submitted to Basic Research Technology Group)	I
E4	Vibration Test of Solid Rocket Motors	I
E5	The Storage Supply and Transfer of Cryogenic Fluids in Space (submitted to Thermal Control Group)	I
E6	Propellant Management Device Design Parameters at zero-g	I
E7	Thruster Induced Back Contamination	I
E8	Supercritical Combustion Measurements in zero-g	I
E9	Pulse Characteristics of Small Thrusters	I
E10	Flight Test of Composite Engine	I
E11	Deployment/Assembly and Control of Large Space Propulsion Energy Sources (Solar Sails, Solar Energy Concentrators, Solar Photovoltaic Panels)	I
E12	Sublimation Properties of Solidified Propellants	I
E13	Flight Test of SEP Thrust Subsystem	II, I
E14	Flight Test of Low Molecular Weight Propellant Bombardment Thruster	II
E15	Space Storability of Solid Rocket Motors	II, III
E16	Measurement of Solid Rocket Motor Thrust Alignment	III

No.	Title	Justification Category
E17	Final Qualification Test of N_2H_4 Resistojet	III
E18	Final Qualification of F_2/N_2H_4 Propulsion System	III
E19	Final Qualification Test of Cesium Ion Engine	III

PART I

ADVANCED TECHNOLOGY REQUIREMENTS

TABLE OF CONTENTS

Introduction

The Propulsion Technology Working Group Report has been divided into two parts. Part I has summarized the Group's effort in identifying and classifying appropriate advanced technology requirements which are consistent with the needs described by the Technology User Group and of the Outlook for Space Study. Part II has summarized the experimental aspects of that technology which might be advantageously carried out in near-earth space using the Shuttle Orbiter, its payload bay, the Spacelab and/or some free flying device that might be used for long-duration testing.

The major goal for propulsion technology was to reduce space transport costs in order to faciliatate all the goals of the space program. Three major thrusts were derived from that goal:

1. Reduce cost of transport from earth to low orbit from 500 $/kg to 50 $/kg
2. Reduce cost of transport from earth to geosynchronous orbit or to earth escape from 3000 $/kg to 500 $/kg
3. Reduce cost of transport from earth to the outer reaches of the solar system from $3x10^6$ $/kg to 3000 $/kg.

The central point of the Group's effort was the Table of Advanced Technology Requirements (Part I, Section 2) which summarizes the propulsion technologies considered during the workshop, along with the technology driver (either a specific type of mission or a new technology opportunity). In addition, the Table has catagorized each technology according to its state of readiness as well as its relationship to the major thrusts identified by the Group.

Part I. ADVANCED TECHNOLOGY REQUIREMENTS

1. Introduction

The objective of the Part I report is to identify and classify those propulsion technology elements that are seen by the Propulsion Technology Group to meet the expressed technology needs of the Workshop Technology User Group and of the Outlook for Space study. This report is intended to be a response to the calls for Mission Driven Technology and Opportunity Drive Technology.

The elements discussed and presented by the Propulsion Technology Group are shown in Table of Advanced Technology Requirements (Section 2) which serves also as a supplemental table of contents. The entries generally are made at the system level rather than the component level. They are categorized in a manner similar to that used in the Technology Forecast of the Outlook for Space study (Ref. 1): first, by the manner in which the energy used for propulsion is obtained (collected in space, stored in electronic or chemical energy states, or stored in nuclear energy states); and second, by the current status of the technology. The status of technology development is an indication of the current technical maturity or of the projected technology readiness date. The table in Section 3 shows the following technology status codes:

Code	Current Status	Readiness Date
A	In Use	Prior to 1975
B	Near Term	1975-1985
C	Far Term	1985-2000
D	Conceptual	Post 2000

The Table of Section 2 lists lists entries by energy category, with technology readiness code letter shown to the right of each item.

In order to relate the identified technology to user (mission) needs, five mission operating regimes were established:

1. Earth to low earth orbit.
2. Low earth orbit to geosynchronous orbit or earth escape.
3. On orbit operations
4. Interplanetary
5. Extraterrestrial operations: orbit insertion, landing and take off, etc.

All space missions identified in the User Requirements and the Outlook for Space drive propulsion technology requirements in one or more of these regimes. Thus, rather than repeatedly list all of the missions supported by each of the technology entries, each entry in the table is identified with one or more of the operating regimes, which is shown in the column entitled, Technology Driver. The reaction to mission needs is thus implied by the operating regimes required for any mission.

All technology entries that are classified as "conceptual" in the Technology Readiness Code column are identified as being "opportunity driven" technology in the Technology Driver column, and are not related to mission operating regimes. The technology in this category has not yet been advanced to the point which parameters are well enough known to establish possible advantageous application; however, the possibilities are sufficiently attractive to encourage advocacy of research.

The objective, description, and justification for each technology entry provided on the Definition of Technology Requirement forms were completed only to the extent that readily available information existed. The said information is summarized in Section 4.

In cases where all or a major part of the propulsion-related technology fell into the purview of the Basic Research Technology Group or another Technology Group, the technology item was referred to that group and only a summary is included in Section 3 in this report for completeness. The referral of these items is indicated in the table of Section 3.

In addition to pursuing the orginal objectives of the workshop, each group was asked to generate some "major thrusts" of the technology in their respective area disciplines. Those generated in the Propulsion Technology Group are also shown in the table of Section 2 in the column entitled Major Thrusts Code. This is further explained in the following section.

4. Overall Observations and Summary of Part I

The workshop initially had two major objectives: firstly to identify experiments and secondly to identify areas of new technology. At the midpoint of the workshop, the Technology Groups were asked to respond to an additional objective: identify from the work to that point some overall goals that might be taken as major thrusts of the technology advances required in the various disciplines represented. The major thrusts identified for Propulsion derive directly from a central goal of propulsion technology: to reduce space transport cost and thereby to facilitate all the goals of the space program. Three major thrusts developed for propulsion are:

a. Reduce cost of transport from earth to low earth orbit from 500 $/kg to 50$/kg
b. Reduce cost of transport from earth to geosynchronous orbit from 3000$/kg to 500$/kg.
c. Reduce cost of transport from earth to the outer reaches of the solar system from $3x10^6$ $/kg to 3000 $/kg.

The cost figures shown were very roughly derived from the possible technology advances forecast in the Outlook for Space study; and these need to be reexamined in more detail if such goals are to be adopted. Nevertheless, cost figures are close enough to realizable goals to show-that possible reductions in the cost of space operations are so great that pursuit of the required propulsion technology could essentially enable several classes of missions outlined in the Outlook study and in the Workshop Users inputs. It should be recognized that a number of goals, equally important but of less sweeping consequences, can also be identified. The desirability of adapting any of these major thrusts as NASA goals must, of course, depend on overall NASA mission planning. The investment required in achieving these goals might be of the order of $\$5 \times 10^9$ total for the first goal and $\$5 \times 10^8$ each for the second and third goals; the investment would be spread over a technology development period of five to ten years.

Several observations can be drawn from the technology requirements discussed by the Propulsion Technology Group and presented herein. These following observations are categorized by the mission operating regimes described earlier.

Earth to low orbit

Large launch vehicle systems will continue to use chemical propulsion exclusively. If heavy lift vehicles in the 10^5 kg payload class are required in future missions, some reduction in transport cost could come about by reducing mission requirements, as compared with those requirements placed on shuttle. For example missions could be flown unmanned, with no return payload and no cross-range on return. Such reductions in requirements, taken together with technology advances to increase engine performance and increase structrual efficiency of the vehicle, will lead to large cost reductions by way of fully reusable mission concepts, even single-stage-to-orbit. A number of the propulsion technology advances identified at the workshop would contribute to these possibilities:

a. High pressure engines burning high-density hydrocarbon fuel with oxygen
b. Composite engines which convert from an air breathing engine to a rocket engine in different operating regimes.
c. Low cost liquid reocket booster engines
d. Large and low cost solid rocket booster motors.

Low earth orbit to geosynchronous orbit or earth escape

The propulsion technologies selected for advanced development in this operating regime will depend heavily on the strategies selected for orbit transfer - the question of resuable vs non-reusable stages.

If fully reusable stages as in TUG designs are selected, then technology entries related to high performance O_2/H_2 engines and to hydrogen storage and handling will have bearing. Alternative higher density propellant combinations, with attendant engine technology, should also be stvdies to determine if hydrocharbon fuels, amine fuels, nitrogen tetroxide oxidizer, or fluorine oxidizer might be used to gain advantages in performance, in packaging, and/or in direct cost.

Large arrays of low-thrust electric thrusters, operated with either a solar or a fission nuclear electric power source, must also be considered for these applications. Key technology drivers of the propulsion device for these approaches will include low system mass and long operating life of the power supplies and the thrusters. Thrusters used in this application might be either electrostatic or magnetoplasmadynamic, using argon as the propellant.

Research on laser generators and laser energy converters may yield prospects for efficient beaming of energy from remote energy sources to reusable orbit transfer vehicles which would be driven by electric thrusters.

If expendable vehicles or combinations of expendable and reusable stages (Ref-2) are selected then the low cost of the expendable stages will be of prime importance and the technology of high-performance solid motors will be directly applicable.

On-orbit

Many of the chemical systems currently being used for orbit operations such as station keeping small orbit modifications and attitude stabilization will continue to benefit from technology refinement leading in increased useable life. As satellite size and design lifetime increase, proportionately more benefits will accrue from the development and use of solar powered electric propulsion systems. The very low thrust (millinewton), precise impulse bit control, and high exhaust velocity of the electrostatic thrusters may make them ideally suited to the attitude modification and stabilization of very large structures, e.g. solar energy concentrators in space.

Interplanetary

The requirements for interplanetary propulsion systems fall into three broad classes.

1) Currently used chemical propulsion systems will continue to find extensive use for accelerating spacecraft to moderately high velocities for interplanetary transit. 2) For higher velocity missions for thrusting requirements closer than about 2 A.U. from the sun (e.g. comet rendezvous or out-of-the-ecliptic probes), use of solar powered electric thruster systems can reduce high velocity stage mass, and, thereby, mission cost, by factors of two to ten, when compared with use of chemical stages. The projected needs for missions of this type define requirements for primary electric propulsion subsystems. 3) For still higher velocity, particularly for missions far from the sun, use of nuclear energy will be required. Examples of such missions to the satellites of the major planets, with mission durations held to a few years. The propulsion approach to the use of nuclear energy is a light-weight multihundred kilowatt, fission reactor with thermionic or heat engine/generator energy conversion providing electricity for electrostatic thrusters. Technology leading to the development of such a nuclear electric propulsion system is clearly required if the solar system is to be fully explored in the next 30 years.

A number of entries in the "conceptual" category are identified as having prospects for matching or surpassing nuclear electric systems. Because of this, research leading to performance potential characterization is required for the following concepts:

a) Energy storage in metastable states (metallic hydrogen, atomic hydrogen, excited states of helium)
b) Nuclear fission fluid core reactors of several types
c) Fusion microexplosions and controlled thermonuclear reaction.

Extraterrestrial

The technology refinements for orbit insertion; deorbit; landing and takeoff in the vicinity planets, satellites, and asteroids are directed to obtaining longer storage and operating life, lower cost, lower mass and to the requirements of tailoring the size and operating conditions to meet specific mission requirements. To date, rockets burning earth-storable bipropellants, nonopropellant, or solid propellants have been used. Completion of the technology required for introducing the use of small fluorine/hydraxine systems to this operating regime well, however, siginificantly reduce mission cost. Systems using fluorine oxidizer approach the ultimate total system performance attainable with chemical propulsion. In addition, use of fluorine in small sealed systems for extraterrestrial operations may open the door for use of fluorine in larger systems operating in earth orbit.

When nuclear electric propulsion systems are brought into being, they can be used to transport spacecraft to the planets, to spiral them into orbit about a planet, and then to spiral them them into orbit about a planetary satellite.

TABLE OF ADVANCED TECHNOLOGY REQUI~~MENTS

I. Chemical Propulsion Technology	Technology (1)* Driver	Technology (2)* Readiness Code	Major (3)* Thrusts Code
A. Stable			
(1) Liquid			
a. F_2/N_2H_4 S/C Propulsion Subsystem	M4, 5	B	(b)
b. Long-Life Hydrazine Technology	M1, 4, 5	A	(b)
c. Long-Life Earth Storable Propellant Technology	M1, 4, 5	A	(b)
d. Adv. Launch Vehicle Engines using High-Density Fuel and Oxidizer	M2	C	(a)
e. Adv. Launch Vehicle Engines using H_2/O_2 Propellants	M2	C	(a)
f. Densification of Cryogens by use of Slush or Triple Point Fluid	M2	B	(a), (b)
g. High Pc H_2/O_2 Upper Stage Engine	M2, 3, 4	B	(b)
h. Tank Head - Idle and Extendable Nozzle for Low-to-Moderate Chamber Pressure H_2/O_2 Space Engine	M3, 4	B	(b)
i. Small H_2/O_2 Main Auxiliary Propulsion Systems	M1, 4	C	(b), (c)
j. High Perf. Space Engines Using High Density Propellants (including dual fuel alternatives to H_2/O_2)	M2, 3, 5	C	(b)
k. Low Cost Liquid Booster Engines	M2	C	(a)
l. High Performance Cryogenic Insulation for Reusable Spacecraft	M1, 3, 4, 5	A	(a), (b)
m. Insulation for Reusable H_2 Tanks for Advanced Boosters	M2	B	(a), (b)
n. High Temperature and High Strength to Weight Ratio Materials for Propulsion System Components	M1, 2, 3, 4	C	—
o. High Performance Structures for Large Launch Vehicles (Submitted to Structures Technology Group)	M2	C	(a)

* See codes immediately following this table.

	Technology (1) Driver	Technology (2) Readiness Code	Major (3) Thrusts Code
p. Composite Engines Technology	M2	C	(a)
(2) <u>Solid</u>			
a. Low Cost Solid Rocket Booster	M2	C	(a)
b. High Performance Solid Kick Motors	M3, 4	B	(b)
c. High Performance Solid Space Motors	M4, 5	B	(b)
B. <u>Metastable States of Matter</u>	O	D	(b), (c)
C. <u>Utilization of Indigenous Materials for Propulsion</u>	O	C	(b), (c)
D. <u>Detonation Propulsion</u>	M5	C	(b), (c)
II. <u>Nuclear Propulsion Technology</u>			
A. <u>Fission</u>			
(1) NEP			
a. Nuclear Electric Propulsion Power Plant	M1, 3, 4	C	(c)
1.) Metallic-Fluid Heat Pipes (Submitted to Thermal Technology Group)	M1, 3, 4	C	(c)
2.) High-Performance Thermionic Conversion (Submitted to Power Technology Group)	M1, 3, 4	C	(c)
b. High-Power Electrostatic Thrust Subsystem	M1, 3, 4	C	(c)
c. MPD Thrust Subsystem Technology	M3	D	(c)
(2) <u>Direct Heating</u>			
a. Solid Core Nuclear Rocket Technology	O	D	---
b. Fluid Core Nuclear Technology	O	D	(c)
c. High Temperature Plasma Core Reactor Fluid Mechanics (Submitted to Basic Research Technology Group)	O	D	(c)

	Technology (1) Driver	Technology (2) Readiness Code	Major (3) Thrusts Code
B. Fusion			
Nuclear Fusion Propulsion Technology	O	D	(c)
C. Radioisotopes			
Combined Radioisotope Thermoelectric Propulsion Module	M1, 4	B	—
III. Collected Energy Technology for Propulsion			
A. Coherent Energy (Laser, Microwave)			
1.) Laser Heating of Propellants	O	D	(b)
2.) Laser and Microwave Electric Propulsion	O	D	(b)
B. Solar Electromagnetic Energy			
1.) Electric (photovoltaic, Dielectric, Concentrator/Heat Engine/Generator)			
a. Auxiliary Electric Propulsion With Hg Bombardment Thruster	M1	B	—
b. Solar Electric Primary Propulsion Thrust Subsystem	M1, 3, 4	B	(b), (c)
c. Electric Propulsion with Low-Molecular Weight Propellants	M1, 3	B	(b), (c)
2.) Solar Concentrator/Thermal Heating			
Solar Heated H_2 Propulsion	M3	C	(b)
3.) Solar Sails (Submitted to Structures Technology Group)	M4	C	—

1.) <u>Technology Driver Code</u>

M - Mission Driven Technology

1. On-orbit operations
2. Earth to low earth orbit (LEO)
3. LEO to geosynchronous orbit or escape velocity
4. Interplanetary transport
5. Extraterrestrial landing, takeoff

O. - Opportunity Driven Technology

2.) <u>Technology Readiness Code</u>

A. In use (Pre-1975)

B. Near term (1975-1985)

C. Far term (1985-2000)

D. Conceptual (post 2000)

3.) Major Thrusts Code - Reduce Space Transport Costs

a. Earth to LEO from 500 \$/kg to 50 \$/kg

b. Earth to GSO or escape from 3000 \$/kg to 500 \$/kg

c. Earth to Outer Reaches of the Solar System from 3,000,000 \$/kg to 3000 \$/kg

Title: F_2/N_2H_4 Spacecraft Propulsion Subsystem

Objective: Design, fabricate, assemble and test a flightweight, pressure-fed blowdown F_2/N_2H_4 S/C propulsion subsystem.

Description: By end of fiscal year 1979, all components which include tankage, valving, thrust chamber, and thermal control will have been developed. During FY 79, the propulsion system will be assembled and checked out. It will then undergo vibration tests, solar/thermal vacuum tests and finally a mission duty cycle test. This final system, which will contain ∿500 kg of propellant and have a thrust level of ∿2700 N, will be flightweight and will be as close as possible to the system that will be used in the first flight project.

Justification: Because of its inherently high-performance, many missions can utilize this type of propulsion subsystem to significant advantage. The performance can be used to reduce mission cost or enhance the mission for the same mission cost. First applications will be planetary orbit insertion. Future applications include planetary satellite landing and take-off and orbit ejection. This technology program will introduce fluorine into space operations thus opening the door to the ultimate performance potential of chemical propulsion.

Title: Long-Life Hydrazine Technology

Objective: Increase the operational life of monopropellant thrusters with emphasis on use of the catalyst bed designs for units with thrust ranging from 10^3 lbf to on the order of 100's of lbf.

Description: Through the fundamental understanding of catalyst bed structure and reactivity, it will be possible to design hydrazine thrusters for longer life. Once the understanding has been achieved, design of thrusters bounding the thrust ranges of interest will take place. Concurrently with design a control thruster using current technology will be tested as a basis for future comparison. Upon completion of design and fabrication, testing will occur. The test results will be compared with the control thruster.

Justification: Hydrazine thrusters of a wide range of thrust levels will continue to find wide-spread use on nearly every planetary spacecraft and launch vehicle and orbiting vehicle system, whenever small total impulse and versatility are called for. Future planetary and earth orbiting applications will require extended operating life.

Title: LONG-LIFE EARTH STORABLE BIPROPELLANT TECHNOLOGY

Objective: Increase the life of earth-storable bipropellant propulsion systems and increase the performance through the substitution of hydrazine for monomethylhydrazine.

Description: Orbiter missions to the outer planets will use moderate energy bipropellants if the requirements permit the cost effective usage of earth storable bipropellants such as N_2O_4/MMH or N_2O_4/N_2H_4. This technology will include new materials for thrusters, the substitution of hard-seat valves for the polymeric seat valves, and finally, the use of hydrazine in place of monomethylhydrazine to improve performance. A system will be fabricated and tested to ensure design adequacy and demonstrate technology readiness. New engine concepts such as bimodal engines will be investigated.

Justification: It is required that earth-storable systems be upgraded to handle the more demanding missions of the future each as outer-planet and satellite orbiters, landers, and sample return missions. Use of N_2H_4 in place of presently-used MMH will extend mission duration and rehability by allowing common tankage of the monopropellant N_2H_4 used in the attitude control system.

Title: Advanced Launch-Vehicle Engines Using High Density Fuel and Oxidizer Propellants

Objective: Conduct the technology needed to permit the development of high performance, high pressure (4000 P_c) reusable rocket engines using high density fuel and oxidizer propellants.

Description: The current state-of-the-art for the high propellant density combination of liquid oxygen and RP-1 is represented by the F-1 engine which operates at about 1000 psi chamber pressure and for the high density earth storable combinations by the Agena Engine which operates at about 500 psi chamber pressure. The technologies for both of these propellant combinations must be advanced considerably and must be almost completely developed for the possibility of using liquid oxygen with the amine fuels or heavy hydrocarbon fuels.

Promising heavy hydrocarbon fuels that when used with liquid oxygen offer higher density-impulse than RP-1 with liquid oxygen must be surveyed and characterized, heat transfer data and fuel thermal decomposition data must be developed along with regenerative cooling techniques with liquid oxygen. Modeling of the combustion process and chamber gas dynamics must be improved to insure that combustion instability can be avoided and energy release efficiency (performance) maximized. An aggressive search for high temperature turbine and combustor materials must be made so that turbine and combustor wall temperatures can be raised and/or cyclic life extended. Composite and filament would technology must be developed for components and interconnects so that engine weight can be minimized. Engine system studies are needed to evaluate performance, engine weight, cooling limits, variations in engine cycle, boost pump drive techniques and development risk.

Justification: Studies have shown that use of high performance, high propellant density engines or dual-fuel engines operating with both high density fuel and liquid hydrogen will enhance launch vehicle performance and may enable single-stage-to-orbit launch vehicles to be realized. In addition, these engines are applicable to future heavy lift launch vehicles and to liquid boosters that could replace the solid rocket boosters on the present Space Shuttle.

Title: Advanced Launch Vehicle Engines Using Hydrogen and Oxygen Propellants

Objective: Improve the technology now being used in the development of high performance, high pressure reusable rocket engines using hydrogen and oxygen propellants.

Description: The current state-of-the-art for high performance, high pressure hydrogen-oxygen engines is represented by the Space Shuttle Main Enginer (SSME) now under development. In order to uprate this engine and provide for the development of even more advanced hydrogen-oxygen engines and/or fuel engines operating with hydrogen and heavy hydrocarbon fuel, the state-of-the-art must be extended.

To attain these goals technology is needed to provide high temperature resistant turbine and combustor materials in order to improve specific impulse and/or extend cyclic life to provide extendible nozzles to better optimize specific impulse to provide long life bearings and seals, and to provide composite or filament wound components and interconnects to reduce engine weight.

Justification: The requirement for high performance, high mass fraction, reusable stages for the Space Shuttle, and future single-stage-to-orbit and heavy lift vehicles has been established by numerous studies and analyses. In order to maximize payload and minimize recurring cost, technology must advance in the areas of specific impulse improvement, weight reduction, and extension of component life.

<u>Title:</u> Densification of Cryogens by the Use of Slush or Triple Point Fluids.

<u>Objective:</u> Generate technology needed to allow for the practical use of slush or triple point cryogens.

<u>Description:</u> Application trade-off studies will be performed to determine the magnitude of payload gains or vehicle size and weight reduction obtainable from use of densified cryogens. Experiments will be performed in moderate sized hardware (4-6 ft. diameter) to determine optimum procedures for manufacture, storage, transfer, and pumping of slush and triple point cryogens such LH_2 and LO_2.

<u>Justification:</u> Advanced space vehicles using hydrogen/oxygen propellants can benefit from increased propellant density through reduction of vehicle size and improved mass fraction. Use of slush or triple point cryogens has the potential for increasing propellant density by approximately 15%.

Title: Tank Head Idle and Extendible Nozzle for Low-to-Moderate Chamber Pressure, Hydrogen-Oxygen Space Engines.

Objective: Provide the technology for increasing the performance of low-to-moderate chamber pressure cryogenic space engines.

Description: The technology for low to moderate chamber pressure cryogenic engines is, in general, in hand; however, effort is needed to demonstrate the weight and performance of extendible, high area ratio nozzles which are needed to maximize performance, and minimize stowed engine length. In addition, tank head idle mode, a viable method of conserving weight and propellant, must be demonstrated.

Justification: Low to moderate chamber pressure hydrogen-oxygen engines are suitable for future space vehicles such as the Space Tug; and because most of the technology is already in hand, represent a low development risk, low development cost approach to satisfying the propulsion needs.

Title: High Chamber Pressure H_2/O_2 Space Engines

Objective: Develop broad based technology for high performance, reusable, long life cryogenic space engines.

Description: Development of technology for advanced, high pressure H_2/O_2 space engines, including: staged combustion cycle, 20,000 pound thrust engine operating at 2000 psia chamber pressure and aerospike 25,000 pound thrust engine operating at 1000 psia chamber pressure.

Justification: High chamber pressure, long life cryogenic space engines provide higher specific impulse, lighter weight, and smaller size, which are advantageous for future space vehicles, such as space tug.

Title: Small H_2/O_2 Main and Auxiliary Propulsion Systems (APS)

Objective: Develop technology for LH_2/O_2 attitude control systems suitable for Space Tug and cryogenic main propulsion systems for apogee kick stages or planetary retro stages.

Description: Cryogenic APS for vehicles like Space Tug requires 25 pound thrust engines capable of high performance, long life, and rapid start-up. System components such as small cryogenic pumps, accumulators, and refillable tanks also are needed. Main propulsion engines of 300 to 3000 pounds thrust need techology work to obtain high performance, light weight and reliability.

Justification: Cryogenic auxiliary propulsion systems provide higher payload capability through high specific impulse and light weight. Cryogenic APS for Space Tug also provides improved abort capability, and improved logistics since only cryogenic propellants are used on the vehicle.

Title: High Performance Space Engines Using High-Density Propellants

Objective: Develop technology for high performance engines in the 5,000 to 30,000 pound thrust class for selected high bulk density propellants, such as LOX-hydrocarbon fuels, LOX-amine fuels, fluorine-hydrogen, or N_2O_4/N_2H_4.

Description: Application studies will be performed to evaluate various high density propellant systems for advanced vehicles and select the most promising ones for experimental work. Technology work will include investigation of engine cooling, component design and performance, engine system analysis, and systems testing. Program will include bell and plug nozzle engines and dual fuel engines capable of burning first LOX/RJ-5 (for example) and then LOX/LH_2.

Justification: Higher performance systems for high bulk density propellants are needed for applications such as advanced orbit-to-orbit transfer vehicles, space maneuvering, and lunar-missions.

Title: Low-Cost Liquid Booster Engines

Objective: Provide the technology needed to develop low cost, low-to-intermediate pressure, pressure-fed or pump-fed, large thrust engines.

Description: Large thrust, low-to-moderate chamber pressure (200-1000 Pc), pressure-fed engines have never been built in the United States. Moderate pressure pump-fed technology for large thrust boosters has not progressed beyond that represented by the F-1 Engine.

The technology needs for the development of large thrust, low-to-moderate chamber pressure, pressure-fed or pump-fed booster engines are in the areas of high strength, low weight composite or filament wound materials for thrust chambers, design and fabrication techniques for their use in large engines, techniques for sealing the engine against sea water prior to water landing or techniques to clean and flush the system if sealing is not feasible. The high and low frequency combustion stability characteristics of large diameter, low resonant frequency combustors must be examined and appropriate injector element and pattern studies undertaken where required.

Justification: Low cost, low-to-moderate chamber pressure engines, operating with inexpensive liquid propellants, could have a near term application as a replacement for the solid rocket motors on the Space Shuttle, thus reducing recurring propellant costs. This booster type could, in the far term, be used to augment the thrust of large, heavy lift vehicles and/or early versions of single-stage-to-orbit vehicles.

Title: High Performance Cryogenic Insulation for Reusable Spacecraft

Objective: Develop technology for high performance insulation systems suitable for use on reusable spacecraft.

Description: Conduct experimental tests of multilayer insulation and other types of high performance systems, such as evacuated, load bearing insulation systems. Evaluate effects of repeated (cyclic) application of typical mission environments, including ground hold, launch, on-orbit operation, re-entry, and preparation for re-use.

Justification: Cryogenic insulation systems are needed that are capable of providing consistent thermal performance and light weight for a large number of re-uses. Present purged multilayer insulation systems tend to degrade in performance due to repeated pressure loading/unloading and due to the effects of atmospheric contamination.

<u>Title:</u> Insulation for Reusable Hydrogen Tanks for Advanced Boosters

<u>Objective:</u> Generate technology for light weight, reusable insulation systems for large scale cryogenic tanks for advanced STS boosters.

<u>Description:</u> Insulation systems will be tested in relatively large scale cryogenic tanks to obtain data on thermal performance of the system and reuseability. Efforts will focus on low weight, low cost, ease of repair, and resistance to thermal cycling.

<u>Justification:</u> Insulation systems are needed for the large scale reusable cryogenic tanks for advanced STS boosters, such as SSTO's or heavy lift vehicles. The stored cryogens must be protected from heat loads during ground hold, launch, and flight to low earth orbit to prevent excessive propellant boil off.

<u>Title:</u> High Temperature and High Strength-to-Weight-Ratio Materials for Propulsion System Components (Submitted to Materials Technology Group)

<u>Objective:</u> Develop higher temperature resistant, longer cyclic life, and lighter weight materials for propulsion system components.

<u>Description:</u> Develop higher temperature resistant materials for turbine blades, stators and housing, and combustors that will permit higher operating temperature and/or increased cycle life. Develop technology for light-weight composite or filament wound structures that can be used for propellant tanks, lines, valves, solid rocket motor cases, and liquid rocket combustors. Examples of composites are Revlar filament and carbon filament in carbon matrix materials.

<u>Justification:</u> The technology advances that have been identified for liquid and solid rocket engines are dependent in large part on the development of materials that will permit turbines and combustors to operate at higher temperatures or with higher cycle lives. Increased turbine temperature leades to increased chamber pressure, area ratio, performance, and thus payload, by extracting higher specific power from the turbine. Increased cycle life reduces refurbishment requirements and thus recurring costs. Lower weight components lead to higher stage mass fraction and increased payload capability.

Title: High Performance Structures for Large Launch Vehicles (submitted to Structures Technology Group)

Objective: Develop the technology to provide the very light weight, highly-efficient integrated structures needed for the low-cost heavy lift vehicles.

Description: In conjunction with the development of new materials such as graphite-fiber composites and propulsion systems, such as engines which can operate as a rocket or make use of the atmosphere, develop the technology for the techniques to more effectively integrate the holding of all of the elements: aerodynamic skin, propellant tanks, thrust elements, cargo bay and propulsion engines together.

Justification: Large heavy lift vehicles can provide low cost transportation, only if the mass fraction is improved. This is especially critical to the use of single-stage-to-orbit vehicles where all inert mass is carried to and from earth orbit. Because of the large projected traffic to low-earth orbit, the payoff on the technology investment can be significant.

Title: Composite Engines Technology

Objective: Develop technology for composite (rocket/airbreathing) engines for advanced horizontal take-off, horizontal landing (HTOHL) shuttle-type vehicles.

Description: Conduct vehicle/propulsion system analyses of HTOHL fully reusable two-stage-to-orbit shuttle vehicles for the post 1990 time period that utilize composite engines. Select engine concept and perform technology program to bring composite engine technology to maturity by 1985.

Justification: The HTOHL two-stage reusable shuttle vehicle using a composite engine has very low recurring cost per launch and low gross lift-off weight for a given payload capability.

Title: Low-Cost Solid Rocket Booster Motor

Objective: Lower cost approaches to large solid rocket boosters so that the next buy of SRB's will cost 50% less.

Description: Three areas: filament wound cases, low-cost nozzle materials, and low-cost case insulation, have been identified as having potential for decreasing the cost of SRB's with equal or greater performance, and there are other approaches for decreasing the cost. However, these lack a demonstration and data to prove that they could be incorporated into the SRB without program risk.

Justification: The three identified areas have had extensive technology efforts in the past and the technology is ready for use except for demonstration against shuttle SRB requirements which is straight forward engineering. Other areas have potential to reduce costs if technology is demonstrated.

Title: High Performance Solid Kick Motors

Objective: Demonstrate technology for high performance solid propellant motors for use in upper stages or kick stages in low cost Tug system.

Description: Kick motors do not exist with more than 1100 kg. of propellant; however, a 2000 kg motor or larger will be needed and will be developed. New technology needs to be developed and demonstrated in complete, integrated flight weight motor hardware to provide cost-effective kick stages.

Examples of these technologies are: Composite case using Kevlar fiber and low density insulation; Nozzle and cases using carbon fiber-carbon matrix materials so that much of the inert case insulation can be eliminated and propellant placed in the volume that was occupied by the insulation, Thrust vector control moveable nozzle system after selection between Lockseal, Techroll-Seal, and Thiovec; Class 2 propellants with high performance; Stop-restart system using class 2 propellants to provide flexibility for solid rocket kick motors.

Justification: The current solid motors used by NASA for upper stages or kick motors were developed during the early 1960's, and the technology in use has not been updated. The maximum kick motor size is 1100 kg, and larger sizes will be needed for Tug. It will be cost effective to develop motors using the latest demonstrated technology. Future DOD efforts for propellants will all be class 7, which cannot be carried on the Shuttle; thus, NASA needs a low-cost high performance class 2 propellant in high performance hardware.

Title: High Performance Space Solid Motor

Objective: Demonstrate the technology for a 300 kg high performance heat sterilizable solid motor.

Description: Conduct a demonstration program after increasing the performance and stability of the propellant system by increasing the solids loading from 81% to 85% to obtain an increase from 280 to 290 sec. The design of the motor is to capitalize on grain stress relief techniques. To complete the demonstration the motor needs to be fabricated, subjected to thermal sterilization cycles and static tested.

Justification: Heat sterilizable high performance motors larger than 70 kg will be needed, the ability to withstand the sterilization environment does not follow linear scaling laws; thus, the capability must be experimentally demonstrated. Preliminary analyses of a mission such as a Mars Sample Return indicate that larger motors are needed and that the mass fraction and specific impulse have large potential payoffs.

Title: Metastable States of Matter

Objective: Determine feasibility of storing and utilizing metastable matter as energy sources for propulsion.

Description: Currently, the metastable states of matter under consideration are metallic hydrogen, excited helium, and mixtures of atomic and molecular hydrogen. Generally, these concepts are under analysis or laboratory investigation. Feasibility or lack of same of storing and using these materials in low mass systems will be demonstrated by analysis and laboratory investigation.

Justification: The storage of energy in metastable states might allow increase in specific impulse by a factor between 5 and 10 over currently envisioned "conventional" chemical propulsion. Payload mass fractions for high-energy missions are very sensitive to specific impulse. This will greatly enhance our capability to perform missions to the outer regions of the solar system if required system mass does not increase greatly.

Title: Utilization of Indigenous Materials for Propulsion

Objective: Provide a broad technology base from which to select schemes and devices for utilizing, for propulsion, the planetary atmospheres, waste products from space activities, and extra-terrestrial surface materials.

Description: The effort will consist of design conception, analysis, and preliminary laboratory exploration of the value of using indigenous materials in particular propulsion mechanizations. Those concepts showing promise when compared to future NASA missions will be subjected to test to determine overall system performance potential.

Some work has been accomplished. It has been demonstrated that solid waste, such as from a spacelab, can be used in a small hybrid rocket to provide auxiliary propulsion; it would be expected that the use of wastes would be the first application of this technology. Work is also being conducted to determine how to use planetary atmospheres, such as the CO_2 on Venus, to provide one component of a bipropellant system.

Justification: Currently all propellant mass must be brought from the earth with 70 to several thousand times that mass being expended to get the propellant mass into space. Thus use of indigenous materials for propulsion can greatly reduce transportation system mass and cost for missions to distant planets and their satellites.

Title: Detonation Propulsion

Objective: Provide prototype demonstration of a detonation propulsion system.

Description: Propulsion in dense high-pressure atmospheres by conventional means is difficult because the mass of the chemical reactors is a function of the difference between the internal and external pressure, while the energy conversion efficiency is a function of the ratio of internal to external pressure in the reactor; thus, as atmospheric pressure increases the required reactor mass increases and efficiency decreases. By detonation of the propellant in an open reactor the chemical reaction takes place at 200 kilo-atmospheres and the reaction is nearly independent of the atmospheric pressure. This approach provides millisecond pulses of thrust which can be used for altitude control or primary propulsion in atmospheres such as Jupiter or other outer planets with pressures of 100 to 1000 bars.

The technology program consists of providing stable high energy detonable propellants which can be stored, transferred and ignited in the reactor; technology development of nozzle reactor chamber refilling techniques, and transfer of the pulsed energy into the payload. Optimum reactor design, prototype system design, and prototype system demonstration would complete the technology program.

Justification: The state-of-the-art technology provides only very heavy low-performing systems for propulsion in very high pressure environments. Detonation propulsion appears to date to be feasible and to yield high performance and potentially low system mass.

Title: Nuclear Electric Propulsion Powerplant

Objective: Demonstrate, in a complete ground prototype test, a fast-spectrum, light weight, low cost, multi-hundred kWe technology for a space nuclear electric power subsystem for primary electric propulsion.

Description: A heat-pipe cooled, fast reactor utilizing Brayton, Sterling, Rankine or thermionic power conversion, is required for the generation of electrical power. The prime contender presently is out-of-core thermionic power conversion. The subsystem also includes a neutron shadow shield, a NaK coolant manifold and heat pipe radiator structures, and some power processing and cabling.

Justification: High-energy planetary exploration at Jupiter, Saturn and the other outer planets is expected to start by the early 1990's, for which NEP will provide exceptional capability at low cost. For large payload transport from LEO to geosynchronous orbit or escape velocity, NEP will allow a 50% reduction of payload transportation cost. For very high velocity transport to the outer reaches of the Solar System, NEP can reduce transport costs by factors of 10 to factors of many hundreds when compared with chemical propulsion.

Title: Metallic-Fluid Heat Pipes

Objective: Acquire the technology for production and space application of economical, durable, effective metallic-fluid heat pipes.

Description: Metallic-fluid heat pipes have potential to transport thermal power densities up to two orders of magnitude greater than those of their ammonia counterparts. Operating temperatures range from those of water heat pipes to over 1,800 K. For example, a lithium heat pipe operating at 1500°C can transport 15,000 w/cm^2 with a 0.1°/cm gradient. However, these reactive heat-pipe fluids combined with low-concentration tenacious contaminants like oxygen, which accelerate corrosion and solution particularly at high temperatures, can cause serious material problems. Effective, economical processing must be established to minimize contaminants and maximize lifetimes. Simple high-performance wick, envelope configurations must be developed to reduce costs, ease fabrication and processing and decrease contamination. Special application problems such as those of the heat-pipe-cooled reactor and of the thermionic-converter, heat pipe module must be solved.

Justification: Nuclear electric power and propulsion must provide for missions requiring over 100 kWe beginning in the 1990's: planetary, earth-orbit, and nuclear-waste-disposal propulsion and large-space-station and lunar-base power. Such systems need light-weight thermal-transport capabilities to handle great power densities at high temperatures with small thermal gradients. Metallic-fluid heat pipes can meet these requirements.

Title: High-Performance Thermionic Conversion

Objective: Acquire the technology for economical, durable, high-efficiency thermionic conversion of heat from various energy sources to electric power for use in a wide range of applications.

Description: Substantial converter-component gains are now possible because out-of-core thermionics allows material and design freedoms forbidden by in-core nucleonics. New configurations to enhance interelectrode ionization should reduce plasma losses by about 0.5 volts. Such arc-drop reductions generally involve significant decreases in cesium pressure and enable severalfold increases in interelectrode spacings. Even with much lower cesium pressures, promising new emitter materials with bare metal work functions near 2eV should yield good emission. And new collector materials should result in cesiated work functions of approximately 1eV. Overall gains of successful integration of these improved components can effect a change of thermionic-conversion efficiencies from near 10 percent to over 30 percent.

Justification: Thermionic conversion is especially valuable for nuclear electric power and propulsion systems because it handles high power densities with high heat-reception and rejection temperatures. These characteristics and projected conversion-efficiency increases mean reasonable space radiators for nuclear electric power and propulsion systems, which generally range above the 100 kWe level. But thermionic converters can also accept heat at much low power levels from any high-temperature energy source like radioisotopes or concentrated solar energy.

Title: High Power Electrostatic Thrust Subsystem

Objective: Demonstrate, in a complete ground prototype test, the technology for a multi-hundred kWe electrostatic thrust subsystem and its associated propellant storage and distribution subsystem for primary nuclear powered electric propulsion.

Description: Design and demonstrate 400 kWe mercury bombardment ion thruster subsystem, with 3-axis contro authority, ancillary power processing, switching and logic, and thermal control technologies for NEP. Subsystem specific mass is presently estimated at 4 kg/kWe. The subsystem is to be designed for a Shuttle-launched, multi-mission NEP spacecraft or reusable tug.

Justification: High-energy planetary exploration at Jupiter, Saturn and the other outer planets is expected to start by the early 1990's, for which NEP will provide exceptional capability at low cost. For large payload transport from LEO to geosynchronous orbit or escape velocity, NEP will allow a 50% reduction of payload transportation cost. For very high velocity transport to the outer reaches of the Solar System NEP can reduce transport costs by factors of 10 to factors of many hundreds when compared with chemical propulsion.

Title: MPD Thrust Subsystem Technology

Objective: Demonstrate, in a complete ground prototype test, the technology for a multi-hundred kWe MPD are jet subsystem and its associated propellant storage and distribution subsystem for primary nuclear powered electric propulsion.

Description: A 400 kWe magnetoplasmadynamic (MPD) thruster utilizing argon as a propellant, with 3-axis gimballing and auxillary power processing, switching and logic is expected to be an important advanced technology for NEP for Earth orbit transfers at exhaust velocity below 30 km/s. The subsystem is to be designed for Shuttle-launched, multi-mission NEP spacecraft or reusable tug.

Justification: Requirements for transport of a multiplicity of payloads from LEO to many orbit locations and very large payloads to geosynchrous orbit and earth escape can be handled most economically with NEP. The MPD arc jet provides a major reduction of mass, cost and complexity for these missions.

Title: Solid Core Nuclear Rocket Technology

Objective: As assessment of application to combined high-thrust/low-thrust missions.

Description: A direct heating, solid core, nuclear rocket technology would provide high thrust upper stage propulsion at a hydrogen exhaust velocity approaching 10 km/s. This should be assessed in combination with low thrust propulsion, as a dual-mode system or as a separate NEP system.

Justification: This technology, because of its high thrust characteristics, perhaps merits re-evaluation in the light of other technologies more recently being advocated. The advantage of relatively high exhaust velocity, however, appears to be partially offset by the large hydrogen tankage requirement. Possible combined high-thrust/low-thrust missions have not yet been studied within the context of planned STS capabilities.

Title: Fluid Core Nuclear Technology

Objective: To complete the experimental characterization and the conceptual design of a high temperature plasma core nuclear rocket system.

Description: Large, very high temperature, fissioning plasma cores in nuclear reactors have the potential of producing high thrust-to-mass propulsion at exhaust velocities up to 50 km/s. Such systems require the storage and/or recirculation of fissionable materials outside the reactor, and a fairly complete separation of fluid flow between the hydrogen propellant and fissioning plasma within the reactor. Both the "open cycle" and "light bulb" concepts of the plasma core nuclear rocket require evaluation.

Justification: Very large, high energy manned missions, such as manned planetary expeditions, may be expected sometime beyond the year 2000. Such missions will require some combination of high thrust and high exhaust velocity propulsion. It is therefore important to carry the plasma core nuclear propulsion to validation of conceptual design in order to allow a good comparison with other systems carred to a higher level of the state of the art. Any further need for technology advancement can then be assessed.

Title: Nuclear Fusion Propulsion

Objective: A continuing assessment is needed of high-energy fusion research as it moves toward experimental demonstration.

Description: Two main concepts have been proposed for the use of nuclear fusion to generate thrust: micro-explosion concepts (laser-triggered) and controlled thermonuclear reactors (CTR). These concepts represent a future opportunity to obtain much higher energy densities than by nuclear fission, and thereby represent a follow-on technology of potential importance.

Justification: Fusion energy systems represent the first possibility for space exploration well beyond our Solar System. Such missions are after the year 2000, but represent an important aspect of future planning. At this time NASA is a technology observer and planner rather than an active participant.

Title: Combined Radioisotope Thermoelectric/Propulsion Module

Objective: To integrate the separately developed technologies of radioisotopic thermoelectric generators and propulsion to enhance mission performance.

Description: Flow passages and thruster nozzles are incorporated in the design of a radioisotope thermoelectric generator so that the propellant is directly heated for specific impulse improvement.

Justification: The radioisotope thermoelectric generator is typically applied to deep space missions where any extention of mission life time is of great value. Increased performance of the auxilliary propulsion system extends useful mission life time and/or capability by conserving propellant.

Some types of sensors are incompatible with high energy propellant exhaust products and force the use of cold gases having low specific impulse. Auxilliary heating can more than double the specific impulse in these cases.